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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

Reduction of GHG emissions through promotion of commercial biogas plants (UNIDO/GEF)

Feasibility Studies – Final Report

Prepared for: UNIDO

Author: Bart Frederiks

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EXECUTIVE SUMMARY

UNIDO, in collaboration with the Cambodian Ministry of Environment (MoE) and Ministry of Agriculture, Forestry and Fisheries (MAFF), developed a GEF project aimed at demonstrating and promoting biogas-based energy services as a financially viable, reliable, effective and sustainable mechanism to achieve access to energy as private sector investment. Underlying report is the result of a series of studies carried out as part of this project. The studies include feasibility studies at 12 pig farms; assessment of the status of 4 existing biogas plants in Cambodia; assessing (alternative) uses for biogas generated and slurry; and exploring the viability of cooperative models for biogas production.

Feasibility studies on biogas production have been carried out at 12 pig farms in 7 provinces all over Cambodia. It concerned farms of different types (fattening / mixed), scales (1,200 – 15,835 heads), and energy supply situations (on-grid / off grid). Recommended digester sizes range from 1900m3 to 14200m3, with generator capacities of 30 to 300 kVA (24 to 240 kW). Of the 12 project, 3 show good to reasonable business potential; 4 show medium business potential and would require some financial support; and 5 have very limited potential. The combined generation capacity of the 7 farms with good or medium business opportunities amounts to 840 kVA (672 kW). The GHG emission reduction potential of these farms amounts to 19,681 tCO2eq/a.

An analysis of the critical factors for project economics reveals the following:

- Project scale is one of the most important factors, because of its influence on investment and operating costs (both subject to economies of scale) and higher technical efficiencies converting biogas to electricity. The two smallest farms have the poorest economic outlook, while the largest farm has the best outlook.
- On-farm energy demand is an important factor, as the rates at which (excess) energy can be sold are always lower than the rates at which energy is currently produced (i.e. with diesel) or supplied (from a grid). Some farms have only little diesel consumption for water pumping, while others are introducing closed barn systems which increases electricity demand. For many farm owners, access to low cost electricity is a prerequisite for switching to more energy intensive farming systems.
- Farms where both maximum electricity production and captive power only scenarios were assessed, show that maximum electricity production cases are generally (much) more economic that captive power scenarios.
- The location of the farm is of importance. On the one hand because farms situated at a distance to the grid would need to invest in the infrastructure required to supply electricity to the grid. On the other hand, electricity demand varies between concession areas, notably between EdC (who is only interested in buying electricity during dry season when hydropower potential is low) and local REEs (whose demand is stable throughout the year.

- Type of farm (fattening or mixed) is of some importance. Most fattening farms run two “all-in, all-out” cycles each year, which means that twice per year the farm is emptied and new piglets are brought in. This results in large fluctuations in dung production, and consequently to biogas and electricity production potential.
- One factor that is found in all farms is the high water consumption, for stable cleaning and (especially) for changing animal bath water.

The performance of four existing biogas plants that were assessed is as well as can be expected. However, gas treatment (particularly H2S removal) is not applied in any of the biogas systems, which affects biogas utilisation equipment lifetime. Also, in most farms there is no gas metering so digester output and / or generator performance is unknown. All farms are recommended to incorporate gas treatment and gas metering. In addition there are company specific opportunities of improving the existing biogas systems including improvements to generators and gas production increases.

In the Cambodian energy market, the possibilities of selling excess electricity depend on the demand of the local concession holder. The most promising conditions for electricity supply to the grid are found in concession areas of rural electricity entrepreneurs (REE's). EdC has indicated only to be interested in buying electricity during the dry season, which means that during a large part of the year no electricity can be sold to the grid.

Alternative opportunities for gas usage are presently limited. In the rural areas where most farms are situated, there is little purchasing power for modern cooking fuels. Upgrading and bottling, for use in households or for automotive uses, requires storage under high pressure (>200 bar) in heavy cylinders. There is currently no client base and under current energy market conditions (low fuel prices), the costs of upgrading, pressurisation and distribution are much higher than the expected revenues.

Digested effluent from biogas systems (digestate) has a considerable nitrogen, phosphorous and potassium content (estimated at 13%, 3% and 6% of dry matter weight, respectively) and can be used as organic fertiliser. Main barrier is the low solids content of the effluent, which is difficult to increase without losing substantial parts of the nutrients. As such, distribution of effluent should be done by truck or irrigation canals, both of which have limited reach. Storage of large quantities of effluent is practically impossible so it can only be applied if and when it is produced. In fattening farms, the “all-in, all-out” system results in considerable fluctuations in digestate dry matter content.

In general, obtaining revenue from carbon credits is increasingly difficult. The scale of the cumulative greenhouse gas reductions from the biogas projects is relatively small; price levels of certified emission reductions are low (between 2-3 US$/tCO2eq); and project development costs and recurring costs are high. The chances of successfully developing a carbon credit project component are deemed small.

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UNITS AND ABBREVIATIONS

Abbreviations

ABR	Anaerobic Baffle reactor
BOD	Biological Oxygen Demand
C/N (ratio)	Carbon to Nitrogen (ratio)
CH_4	Methane
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
CO_2, CO_2eq	Carbon Dioxide (equivalent) (in Greenhouse Gas accounting)
CSTR	Continuously Stirred tank Reactor
DM	Dry Matter
EAC	Electricity Authority of Cambodia
EdC	Electricité du Cambodge (Electricity Company of Cambodia)
KHR	Cambodian Riel (1,000 R = 0.25 US$; 1 US$ = 4,000 R - Feb 2014)
GHG	Greenhouse Gas
ha	Hectare (unit for surface area), 1 ha = 10,000 m^2
H_2S	Hydrogen Sulphide
HRT	Hydraulic Retention Time
IRR	Internal Rate of Return
K	Potassium
LPG	Liquefied Petroleum Gas
MAFF	Ministry of Agriculture, Forestry and Fisheries
MoE	Ministry of Environment
N	Nitrogen
NPV	Net Present Value
NH_3	Ammonia
NH_4	Ammonium
O&M	Operation and Maintenance
ODM	Organic Dry Matter
P	Phosphorous
REE	Rural Electricity Entrepreneur
TS	Total Solids
UASB	Upflow Anaerobic Sludge Blanket
US$	United States Dollar

Units

A	Ampere (unit for electrical current)
a	year
°C	degrees centigrade
d	day
g, kg, mg	gram, kilogram (1kg = 1000g), milligram (1mg = 0.001g)
kJ, MJ, GJ	Kilojoule, megajoule, gigajoule (unit for energy), 1 GJ = 1,000 MJ = 1,000,000 kJ
kV	Kilovolt (unit for electrical tension), 1 kV = 1,000 V

kVA, MVA	kilovolt-ampere, megavolt-ampere (unit for electrical apparent power)
kW, MW	Kilowatt, megawatt (unit of power), 1 MW = 1,000 kW= 1,000,000 Joules/second *(NB the suffix –e (kWe, MWe) indicates electrical power)*
kWh, MWh	kilowatthour, megawatthour (unit for energy), 1 MWh = 1,000 kWh = 3.6 GJ
l	litre
m^3	cubic metre *(NB when used as unit for biogas quantities, m^3 refers to a cubic metre under normalised conditions of pressure and temperature, i.e. at 20 °C and 1 atmosphere)*
ppm	Parts per million
t	ton = 1,000 kg
%wt	% on weight basis
%vol	% on volume basis

1 INTRODUCTION

1.1 Background

Cambodia has one of the lowest electrification rates in Asia, owing to its poor investments in the electricity sector and inadequate exploitation of available renewable energy (RE). According to the Electricity Authority of Cambodia, the electrification rate in 2015 was 55.37% (in term of families) or 61.7% of all villages.

In the absence of grid electricity provision, small independent private entrepreneurs, i.e. Rural Electricity Enterprises (REEs), supply electricity to the nearby areas using diesel generators to satisfy the rural electricity demand. Electricity production from diesel for captive use in agro-industries especially commercial livestock farms is still commonly practiced. Usage of diesel generators further increases Cambodia’s vulnerability to climate change. Biogas based mini-grids hold great promise for Cambodia in addressing climate change risks and providing access to energy for its whole population.

UNIDO, in collaboration with the Cambodian Ministry of Environment (MoE) and Ministry of Agriculture, Forestry and Fisheries (MAFF), has developed a GEF project aimed at demonstrating and promoting biogas-based energy services as a financially viable, reliable, effective and sustainable mechanism to achieve access to energy as private sector investment. The activities under the project will augment the usage of biogas technologies for electricity generation or other viable options in commercial animal farms by converting the methane emitted from animal waste into energy for productive uses in Cambodia.

The project has four project components:

1. Creating awareness on climate change and building technical capacity in commercial biogas based mini-grids;
2. Creating an enabling environment for investments by private sector in commercial biogas technology;
3. Demonstrating biogas and mini-grid technologies in commercial farms;
4. Monitoring and evaluation.

Underlying report is one of the outputs of component 3, which aims at carrying out feasibility studies at 11 farms with a combined biogas-based generation capacity of 1.5 MWe.

1.2 Objectives

As described in the Term of Reference of the study, the objectives of the work are as follows:

- Conducting techno-economic Feasibility Studies, including identification of appropriate technologies and best uses of produced biogas, in 11 pig farms;
- Assessing the current status of the existing biogas plants installed in 3 other companies, including 2 pig farms and 1 starch factory;
- Identifying and advising other appropriate uses for biogas generated and slurry;
- Exploring the viability of cooperative models for appropriate biogas uses for suitable locations (i.e., clustering of farms), especially in Siem Reap province.

Eventually, the team visited a total of 16 sites: Feasibility Studies were carried at 12 farms, and a total of 4 existing biogas units were visited and assessed. A map indicating the different locations is included in Annex 1.1.

1.3 Methodology

During two missions, 16 visits were made to 15 pig farms and one starch factory. In each company, interviews were held with farm owners, managers and/or operators, in order to collect operational data on dung production, water consumption, energy use etc. (see Annexes 1.2 and 1.3). The information collected through these interviews formed the main source of data for the studies. Additional data on biogas potential, typical per-animal dung production, slurry nutrients etc. was collected from literature sources.

Where possible and deemed necessary, measurements were carried out as a means of assessing or verifying key information

- Water usage is not recorded in any of the visited farms and is largely unknown. Water flow measurements were carried out in order to estimate water consumption for stable cleaning.
- In a number of farms, manure and/or waste water samples were taken, which were analysed in a laboratory in Phnom Penh in order to verify dung characteristics
- In some farms it was possible to assess electricity consumption and load patterns with the use of a power logger.
- In the existing biogas plants, biogas composition (CH_4, CO_2 and H_2S) was measured with a biogas analyser.

In addition, a series of interviews were held with representatives from Electricité du Cambodge (EdC), the Electricity Authority of Cambodia (EAC), and several actors in the field of biogas plant construction and animal husbandry. An overview of all people interviewed is included in Annex 1.2.

Financial analyses were carried out using existing spreadsheet models following the methodology described in Behrens and Hawranek (1991).

1.4 Reading guide

This report contains the full results of the work carried out. It includes 16 chapters; because of potentially sensitive information, it has been divided over four volumes:

- Volume 1 encompasses Chapters 1-3 and the main annexes. Chapter2 presents background information on biogas production and utilisation (including biogas bottling); market conditions for electricity in Cambodia; the use of digester effluent as fertiliser; and the contact details of technology suppliers (Objectives 3 and 4). It is intended for general access.
- Volume 2 includes Chapter 3, presenting the results of the assessment of 4 existing biogas plants (Objective 2). Its dissemination should be restricted; individual sub-sections could be shared with the respective biogas plant owners. It has one annex containing an assessment of a project under consideration by one of the companies.

- Volume 3 is itself divided in 12 parts, each containing the results of the feasibility studies at each of the 12 farms (Objective 1). Each part should be shared only with the respective farm owner; full financial fables are included to each part.
- Volume 4 includes Chapter 16, presents the conclusions and recommendations. It is intended for restricted dissemination.

2 GENERAL NOTES ON BIOGAS PRODUCTION AND UTILISATION

2.1 Introduction to biogas production

Biogas is the product of the anaerobic digestion process, i.e. the bacterial decomposition of organic material (substrate) in absence of oxygen. It is a natural process that can take place when basic conditions are met, i.e. absence of oxygen, presence of sufficient water and bacteria, and suitable environmental conditions (e.g. temperature, acidity). As such it occurs naturally in for example landfills, biomass stockpiles, sludge deposits and swamps; in biogas systems the conversion process takes place inside a reactor.

Biogas itself is a flammable gas that contains mostly methane (CH_4, 50-70%) and carbon dioxide (CO_2, 25-40%), and furthermore smaller quantities of other components such as water vapour (typically <5%), hydrogen sulphide (H_2S) (typically <0.5%) and sometimes traces of nitrogen and oxygen. The eventual composition of biogas depends on the used substrate and process parameters. The Net Calorific Value of the gas depends on its composition but a typical value is around 21 MJ/m^3 for a gas containing 60% CH_4. Biogas can be used for cooking and lighting, and (in larger quantities) for electricity generation and motor driven applications.

There are several parameters that influence the anaerobic digestion process (Eder & Schultz, 2006), including but not limited to:

- Substrate properties. The organic components in the substrate are transformed by bacteria so ultimately it is the organic solid content in the substrate that determines the potential gas yield. Furthermore, some organic substances (e.g. sugars, starch, proteins) decompose more easily than others (e.g. celluloses, lignin). Other important parameters are substrate acidity (pH), nitrogen content relative to carbon content (C/N ratio) and absence of toxic and antibiotic materials.
- Water. The different types of bacteria require an aquatic environment to reproduce so moisture content should be at least 50%. For continuous digester types, slurry-type substrates are most suitable, which in practice means that water has to be added to arrive at the required composition (at least 85-90% water).
- Temperature. Anaerobic digestion can take place between roughly 0 and 70°C. Three different temperature ranges can be distinguished: i) psychrophilic temperature range, occurring at temperatures below 20°C; ii) mesophilic temperature range between 20-40°C with an optimum between 35-38°C; and iii) thermophilic range between 50-55°C. Apart from the temperature regime, temperature stability should be strived for: fluctuations of more that 1-2°C per day should be avoided.

Important system design parameters are (hydraulic, solids) retention time and organic loading rate. The retention time indicates the average time that the substrate resides inside the reactor; it should be long enough to allow a high level of conversion of the organic matter, and to allow the bacteria to multiply (avoid washout), but it should be kept within bounds in order to limit digester size (investment costs). The loading rate is the amount of organic material that can be introduced per m^3 of digester volume per day, under normal operating conditions; for straightforward systems, a loading rate of about 2-3 kg/m^3/d should be considered maximum.

Inside an anaerobic digestion reactor, the conditions are, to some extent, optimised for the conversion process. In addition, the reactor allows efficient collection and evacuation of the produced biogas. There are dozens of different reactor types[1]; the most widely used types are the following:

- Tank reactors are the most straightforward type of reactor, used in scales of several m^3 to several hundreds of m^3. They typically consist of an underground confined space, built in masonry or concrete; without heating or stirring, they operate at ambient temperatures (usually 20-25 °C). Examples are households systems (fixed dome, floating dome) found in millions of households around the world. Advantages are their low complexity, robustness and low space requirements; disadvantages are their costs and limitations to easily digestible materials.
- Continuously Stirred Tank Reactors (CSTR) are larger, more industrial type of digesters (from several hundreds of m^3 upward). They are built aboveground, usually in concrete, and are fitted with stirrers and heating systems. They are optimised for high throughput (short retention times) and can be used with a wider range of feedstocks. Disadvantages are their higher complexity, higher investment cost and higher cost of operation and maintenance. Also, heating requires the presence of a heating source, which in practice means a mandatory combination with a generator (CHP) producing waste heat.
- Covered lagoon digesters are typically found in larger agro-industrial settings, e.g. in large farms, palm oil production, slaughterhouses. In their most straightforward form, they consist of a PVC or HDPE cover that captures the biogas produced by decomposing organic matter inside a lagoon. They are typically large (thousands of m^3) but low cost, but their application is usually limited to easier digestible materials. They can be fitted with stirrers which increases their effectiveness and feedstock application range, but adds to the investment and O&M cost.
- Waste-water treatment systems are primarily intended for removal of organic matter from (low solids content) waste water. They typically feature immobilised bacteria residing in a reactor, converting the solids from the wastewater as it passes by. Examples are Sludge blanket reactors (UASB), Baffled reactors (ABR) and Anaerobic filter. Advantages are their short hydraulic retention times and high COD removal rates; disadvantages are their relative complexity and costs.

Most frequently used systems in the piggery sector in Southeast Asia are covered lagoon systems, because of the large volumes of waste and the low system costs. Also in Cambodia, covered lagoon systems are operational in the range of several thousand to several tens of thousands m^3 digester volume (see chapter 3).

2.2 Pig manure attributes

Dung properties (DM, ODM, C/N)

A total of 9 fresh manure samples and 2 waste water samples were collected at the different farms and analysed for dry matter and organic matter, nitrogen and ammonia contents (see annex 1.4). The results are as follows:

[1] For an extensive overview of biogas technology and applications, see e.g. Deublein & Steinhauser (2011)

- Dry matter content (DM): DM content of the manure samples ranged from 22% to 43%; disregarding the outliers, the average is 32%. The DM content of the waste water samples were 1.6% and 2.1% but it is unknown whether these were representative to the average waste water.
- Organic dry matter content (ODM): ODM as % of DM ranged from 78% to 88%, with an average of 83%. Of the waste water samples it was 88% and 81%.
- C/N ratio: Nitrogen contents of the solid manure samples ranged from 1.5 to 4.3% of DM. With an estimated carbon content of 50%, C/N ranged from 10-26 (13 on average). The C/N ratio of the samples of liquid waste (including urine) was 13.
- Free ammonia (NH_3): NH_3 contents in the samples ranged from 0.11-0.24% of fresh samples. Dilution with flushing water (>1:20) will prevent process inhibition. Of the waste water samples it was 0.02% and 0.08%.

Dung production (kg fresh / dry)

Dung production per head per day depends strongly on animal age, weight and type, and corresponds closely with feed intake.

- For fattening pigs, most sources report dry matter production from <0.1kg/head/d for piglets below 20kg, to 0.3-0.5 kg head/d for animals in the last part of the fattening process. Vu Dinh Ton & Nguyen Van Duy (2009) carried out measurements in Vietnam, and found (fresh) dung-to-feed ratio varies from approx. 0.60 to 0.45 for small and large fattening pigs respectively; over the fattening process this was 0.49 with a total fresh dung production of 127 kg/head (0.25–0.30 kg DM/head/day). Typical average feed intake of fattening pigs in Cambodia is around 1.4 kg/head/d, resulting in a value of 0.25 kg DM/head per day which will be used in this study.
- For sow with litter, dry matter estimates from sources range from 0.57–1.32 kg DM/head/day; for sow without litter 0.28–0.78 kg DM/head/day. An overall value of 0.50 kg DM/head/day is used in this study.
- For boar, estimates range from 0.57–0.88 kg DM/head/day. A value of 0.70 kg DM/head/day is used in this study.

Urine production

Following FAO (1988), urine production is estimated at average 2.5 litres per day for fattening pigs, and 5 litres per day for boar and sow. This is consistent with other sources (e.g. Canh et al, 1997). Dry matter content indications from literature vary between 0.5-5%; 2% is used in this study.

Biogas production

Indications of biogas production from pig manure typically range from approx. 300-450 m^3/kg ODM, with 400 m^3/kg ODM as an average value (Eder & Schultz, 2007). With ODM making up on average 83% of DM, gas production would be 332 m^3/kg DM; a conservative value of 300 m^3/kg DM is used in the study.

Note that the extent to which the biogas production potential is actually utilised largely depends on the temperature inside the biogas system and the chosen retention time. Climatic data in the different regions show average annual temperatures in the range of 27-28 °C for all regions, with monthly averages varying with 1-3 degrees. As far as ambient temperatures go, these conditions are favourable for anaerobic digestion.

A retention time of 30 days is selected as a standard, which is typically applied by suppliers in the region. After this period, additional biogas production is minimal.

Methane content of biogas measured at different installations in Cambodia varied between 65% and 72%, with an average of 67%. This brings the Net Calorific Value of the gas at approx. 23 MJ/m^3. Hydrogen sulphide (H_2S) values measured at the different installations varied between 450-750 ppm with an average of 600 ppm. Depending on the composition of the dung, H_2S levels may reach levels above 1000 ppm (e.g. Lien et al (2014), Nijaguna B.T. (2002)).

2.3 Pig rearing practices encountered

During the course of the study, a total of 15 pig farms of different types and sizes have been encountered. Although each of the farms is described in the different chapters 3-15, some general trends are described below.

Eight of the farms visited are fattening farms. The majority of these farms are working under contract of C.P. Cambodia, a large feed and livestock company. Under this agreement, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months; C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

C.P. practices an “all in, all out” system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease. C.P. indicated that this is critical to their operations, and they would not consider changing it.

Figure 1: Interior of a fattening stable

Figure 2: Interior of a sow stable

6 of the visited farms are mixed farms, featuring both pig breeding and fattening. These farms hold sows and boars, and have different facilities for pregnant sows, suckling sows (i.e. with piglets), weaners (piglets being trained to feed on prepared feed) and fattening pigs. There is a remarkable difference between different stables – their interior layout and the way in which there are cleaned. Stables for fattening pigs are divided in a few dozen holding pens, each holding 20-25 pigs. Each pen has a bath which is regularly changed (usually every day); after this, the pens are hosed down (every day or several times per week). Sows are kept individually; their stables are usually cleaned by removing solid dung and subsequent hosing.

Only one of the farms was a breeding farm, producing piglets for fattening on other farms.

A further distinction can be made between open stables and closed stables. Most stables are open, with natural ventilation. However, some of the farms have switched to (or are in the process of switching to) closed stables. These stables are fitted with mechanical ventilation (draught fans in the back of the stable) and a water curtain in the front of the stable as a means of air cooling. This improved control over the interior climate leads to improved metabolism and thus to better growth. Energy demand is considerable, estimated in the range of 25-50 kWh/stable/d.

Figure 3: Water curtain of closed stable

Figure 4: Draught fans in the back of closed stable

Estimated average water consumption for stable cleaning varies between 19 and 48 litres per head per day, with an average of 37 l/head/d. Water is usually pumped from boreholes or ponds; in one case, water was piped from a spring in a nearby mountain range. In one case, water shortages posed a problem, and water had to be brought in by truck during dry season.

Estimated total waste production (including urine, but net of evaporation) varies between 21 and 50 l/head/d, with an average of 40 l/head/d. Waste water usually flows into one or more ponds on the premises, and not processed further. From the ponds, the water will evaporate or find its way into the ground water. Most of the solids decompose; some will leach into the ground, while others will slowly accumulate over time in the pond. In some cases, part of the slurry is used for the fertilisation of fields and/or trees on the farm premises.

2.4 Biogas applications

2.4.1 Electricity production

For non-household / institutional biogas systems, the production of electricity is the most widely used biogas application. Conversion of biogas into electricity is typically done in three ways[2]:

- In conventional diesel generators, running in dual fuel mode. By adding biogas to the combustion air, diesel consumption can be reduced up to approx. 80%; some diesel is still required for ignition and for cooling the injectors. Typical fuel replacement is around 0.4 litres of diesel per m^3 of biogas. Because of the relatively large volume that biogas

[2] Fuel Cell technology is also suitable for biogas; it is highly efficient, clean and reliable but the investment costs are still prohibitive - from 6500$/kW for a 1.5MWe CHP system (McPhail et al, 2012) to more than 30,000$/kWe for a 1kWe micro-CHP system (Ammermann et al, 2015)

occupies in the gas/air mixture, some engine de-rating (10-20%) can be expected. This is a straightforward method that can be economic when there is already a diesel engine present, and diesel prices are high; disadvantage is the continued consumption of diesel which adds to the running costs.

- In generators fitted with a gas (spark ignition) engine, which can run on 100% biogas. Gas gensets are usually somewhat more expensive than diesel gensets (approx. 400-800 US$/kW in the 50-500 kW range), which is off-set by the lower running costs. Conversion of (used) diesel engines is also possible, by adding a spark plug system and gas / air mixing device, and decreasing engine compression ratio; this results in even lower investment costs (100-200 US$/kWe). Typical efficiencies are in the order of 30-35% for systems above 50 kWe, and can approach 40% for capacities over a few hundred kWe.
- In gas turbines, from about 30 kWe upwards. These systems have similar efficiencies as gas engines but have the advantage of tolerating lower quality gas. Their running costs are lower but investment costs are higher (approx. 2,000 US$/kW in the 50-100 kWe range).

Note that engine applications as described above may also be applied to mechanical drive systems (shaft power) such as water pumping and mill powering.

In general, scale has a large impact on electricity production economics. At increasing scales, investment costs per kW go down and efficiency goes up. In addition, the biogas production itself is also subject to economies of scale. Combining the waste from different farms can thus be interesting, if they are located in the direct vicinity – transport costs of waste adds considerably to the costs. This option has been considered for two of the farms investigated.

With respect to dual fuelling, this option has been considered for those pig farms in the feasibility study where considerable quantities of diesel are used for energy production. However, these systems address only (part of) the diesel consumption, and are thus typically smaller than systems that are scaled to resource (dung) availability. The reduced scale and the low diesel price appear to make this option less attractive than alternatives.

For all conversion technologies, gas treatment is paramount. This includes removal of water vapour and (especially) H_2S, see also section 2.4.3 below. Typical upper limits for H_2S are 100-200 ppm.

The production of electricity also results in considerable quantities of heat, which can be recovered for on-farm use. Most of the heat - from the engine cooling water - has a temperature of around 80°C. It could be used for heating – e.g. of piglets that need additional warming during the first weeks after birth. The investment in a hot water infrastructure and heating systems can be considerable, and is likely to be economical only where heat is required continuously, i.e. on farms with breeding.

With respect to the final use of electricity, one can distinguish between captive use (for meeting electricity demand on the farm) and (additional) supply to other consumers, e.g. through minigrid or national grid.

- If only captive use is met, production is typically lower than when (excess) electricity is also supplied to others. Less biogas is then required, so the biogas system can be somewhat smaller. However, the generator will need to meet peak loads on the farm so depending on the load pattern, it might be relatively large in comparison to the electricity it produced. Its utilisation rate will thus be smaller.

- Supplying electricity to other consumers requires additional infrastructure – transmission or distribution grid lines, transformer, and/or synchronisation panel. Also, in the case of local distribution through a minigrid, administrative costs (billing) add to the costs.
- In many cases, the revenue or cost saving for captive power is higher than that for electricity supplied to other consumers. Especially when electricity is supplied to the national grid, feed-in rates are usually lower than electricity tariffs paid by the farm.

2.4.2 Biogas piping

Instead of converting it to electricity and/or heat, it is also possible to distribute biogas for use elsewhere. The simplest way is by distributing it through pipes. For nearby users, within a few kilometres, distribution can be done using a low-pressure pipe network (e.g. in Saint Louis, see box). Typical pressure is in the range of 30-100 mbar, depending on the length of the network. The biogas needs to be cleaned (removal of H_2S because of its toxicity), and moisture content must be reduced in order to avoid formation of condense that could cause blockages in the pipes.

> ***Box: local distribution of biogas***
>
> Since 2012, the abattoir in Saint Louis (Senegal) operates a small biogas system for treating slaughterhouse waste (Bioeco, 2012). The biogas, some 25m^3/d, is produced from rumen contents, dung, blood and waste water. It is cleaned (removal of H_2S and water vapour) and distributed to 15 households in the vicinity. Gas usage is metered at the client; households pay approx. 0.45 US$/m^3 which is comparable to what they would spend on LPG or charcoal.
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The (economic) sense depends mainly on the level of investments, and the willingness and ability of clients to pay. The price of gas delivered should match the costs of the nearest alternative household fuel – differences in utilisation efficiencies included. For example, if the price of LPG (45 MJ/kg) is 0.58 US$/kg (price level found in rural areas – 1400 KHR/l) and the thermal efficiency of a typical LPG stove is 50%, then the equivalent price of biogas (23 MJ/m^3, stove efficiency 40%) would be 0.24 US$/m^3. This price should cover all supply costs, including the costs of biogas production, cleaning and distribution as well as any administrative costs associated with gas distribution (i.e. billing). It compares favourably to the gas value when it would be used for electricity supply to the grid (0.17 US$/m^3 at a feed-in rate of 0.10 USD/kWh and a conversion factor of 1.7 kWh/m^3) but unfavourably to captive electricity production (0.26-0.34 USD/m^3 at electricity prices of 0.15-0.20 USD/kWh and a conversion factor of 1.7 kWh/m^3). Administration costs related to electricity production are much lower or even nil (in case of captive electricity production).

Note that if households use lower cost fuels (e.g. fuelwood), then the equivalent biogas price would be lower. This is often the case in rural areas, where the biogas would be available.

Another option is injection into existing natural gas distribution systems. For this purpose, biogas needs to be upgraded to match natural gas quality standards: this typically requires the removal of H_2S and other impurities, (part of) the CO_2, and the water vapour. Depending on the place where the gas is injected, gas pressure may subsequently need to be elevated to a few bar pressure. The economics largely depend on the price levels for natural gas in the country.

The absence of a gas grid in Cambodia makes the latter option not applicable. Moreover, interviews with villagers nearby some of the visited pig farms point out that the vast majority of households cook on wood that is collected by members of the household, and that there would be little demand for an alternative fuel that would have to be purchased. Piping of biogas is thus not investigated further in this study.

2.4.3 Biogas bottling

Upgrading and bottling of biogas is a third option for distribution for household uses (cooking) and automotive uses. The gas is then cleaned, upgraded to a high methane level (typically >95%) and pressurised.

Water vapour reduction

Raw biogas is saturated with water vapour. The percentage of water contained in the biogas varies with its temperature and pressure; under atmospheric pressure, and a temperature of 35 °C, water vapour takes up about $5\%_{vol}$ of the total gas. At 20 °C, the water vapour takes up about $2\%_{vol}$ of the biogas.

The main problem with water vapour in gas is that this water can condense when the gas temperature drops, or the gas pressure increases. This water can cause blockages in distribution systems, and can lead to corrosion of metallic parts in contact with the gas. Furthermore, water vapour takes up space and thus reduces the relative amount of other gases. By removing the water, the volume of the biogas is reduced but also to a small extent its heating value.

Removal of water is typically done by cooling the gas, which causes part of the water vapour to condensate. This condensate is captured and removed. Once the gas reaches ambient temperatures, it is no longer saturated with water, so that temperature drops and pressure increases do no longer cause condensation.

H_2S removal

Hydrogen sulphide (H_2S) is a colourless, flammable gas that is commonly found in biogas albeit in small quantities (<1% or <10,000 ppm). It originates from the breakdown of proteins – the use of high protein substrates results in higher levels of H_2S in the biogas. It is noticeable from its "rotten-egg" at small concentrations only (<100 ppm) as higher concentrations quickly affect the sense of smell.

Despite the small quantities, H_2S is an undesirable component for two reasons:

- Safety. H_2S is very poisonous, leading to respiratory symptoms at prolonged exposure to levels above 10 ppm, and near immediate death at levels above 500 ppm (Doujaiji & Al-Tawfiq, 2010). The build-up of gas in a poorly ventilated room may lead to potentially dangerous situations.
- Corrosion. H_2S is corrosive, and can deteriorate exposed metallic parts. Moreover, after combustion, H_2S leads to the production of sulphur dioxide (SO_2) and sulphurous (H_2SO_3) and sulphuric (H_2SO_4) acid which dissolve in engine oil, causing it to become acidic. For

this reason, most engine manufacturers indicate a maximum for H_2S, typically 100 or 200 ppm.

There are several methods for the removal of H_2S from biogas[3], the most common being:

- Biological removal. H_2S can be converted sulphur and/or sulphate by micro-organisms. As these micro-organisms are aerobic, this type of treatment requires injection of small quantities for air (<5% of the biogas volume) into the gas holder. This type of H_2S removal is rather crude and may require further removal steps.
- Chemical removal. H_2S reacts readily with iron compounds. By passing biogas through solutions containing iron ions, or passing it through a bed of oxidized iron particles (e.g. iron shavings, steel wool). The H_2S reacts to iron sulphide and water; afterwards, the iron sulphide can be regenerated with oxygen and water.
- Physical removal. H_2S can be removed by scrubbing with (pressurized) water or adsorption with activated carbon.

CO_2 removal

The carbon dioxide contained in biogas is an inert fraction, which takes up space without adding to its calorific value. Its removal, albeit complicated, leads to efficiently store and distribute the gas. The most common technologies for removing CO_2 include:

- Scrubbing with water. Solubility in water of carbon dioxide is about 20-30 times higher than that of methane (depending on temperature). This makes it possible to remove CO_2 by scrubbing, which leads to the CO_2 to go into solution and (most of) the methane to pass through. The water can be regenerated by allowing the CO_2 to escape under lower pressures. As an added advantage, H_2S and ammonia are removed by scrubbing as well.
- Chemical scrubbing with sodium hydroxide (caustic soda) solution. The CO_2 in the gas will react with the sodium hydroxide, forming sodium carbonate.
- Pressure swing adsorption. This technology employs selective adsorbents (e.g. activated carbon, molecular sieves) to capture CO_2 molecules from pressurised biogas, leaving the methane molecules pass by. After the adsorbents are saturated, they are regenerated by letting exposing them to lower (sometimes sub-atmospheric) pressures.
- Membranes. Membranes are porous materials that selectively allow some types of molecules to pass (e.g. CO_2), and retain others (e.g. CH_4).
- Cryogenic purification. This technology makes use of the different thermodynamic properties of CO_2 and CH_4, i.e. the difference temperatures at which each of the gases liquefy under elevated pressures.

Energy requirements for CO_2 removal through water scrubbing (mainly for pressurizing water and gas) are approx. 0.25 kWh/m^3 of raw biogas (Vijay, 2015).

Pressurisation

As methane does not liquefy at room temperature (its critical temperature is -83 °C), it will need to be severely compressed in order to reach acceptable energy densities[4]. The upgraded

[3] It is also possible to avoid the formation of biogas by adding iron salts to the substrate, e.g. iron chloride. This results in the formation of iron sulphide and sulphur which remain in the slurry.

and compressed biogas will be similar to compressed natural gas (CNG[5]) which is typically compressed to 200-250 bar.

Because of the high pressures, the gas needs to be stored in thick-walled steel vessels such as those used for other highly compressed gases such as oxygen and CO_2. Such bottles themselves weigh considerably: a 40l bottle weighs some 50kg. In case of household applications, such bottles would need to be distributed by truck.

The pressurisation of the upgraded gas is typically done with a multistage compressor, which increases the gas pressure in steps while evacuating the heat that it formed by compression. The work that is required for compressing upgraded biogas to 200 bar is approx. 0.9 MJ/m^3 (0.27 kWh/m^3); on raw biogas this is approx. 0.15 kWh/m^3 (Vijay, 2015).

Case study

In order to determine the economic sense of biogas upgrading and bottling, the following case study presents the approximate costs and revenue of a 50 m^3/h, or 400 m^3/d biogas upgrading and bottling plant. The plant is based on Indian technology developed at IIT in Delhi, India, as described in (Vijay, 2014, 2015). The upgrading and bottling plant features a water scrubber for the removal of CO_2 and H_2S; a biogas dryer and a three-stage compressor. The unit produces approx. 27 m^3 of upgraded biogas from 50 m^3 of raw biogas. Annual raw biogas processing is 120,000 m^3/a.

Two potential applications of the bottled gas can be distinguished:

- Households. On the basis of average household wood fuel consumption (14 kg/household/day (SNV, 2004), potential consumption of 1m^3/household/d of upgraded biogas (methane content >95%, calorific value 35 MJ/m^3) can be assumed. In a 40l gas cylinder, 8 m^3 of upgraded biogas can be stored, so the cylinder should be replaced on average every 8 days. LPG prices found in rural areas are around 1400 KHR/l (0.58 US$/kg), so the equivalent price for a bottle of upgraded biogas would be 3.61 US$.
- Automotive uses. This will require modification of gasoline cars, fitting the engine with a provision for mixing air and methane. On the basis of gasoline prices in rural areas (2800 KHR/l = 0.70 US$/l), the price level of upgraded biogas would be 5.16 US$ per 40l cylinder. In comparison to diesel (2000 KHR/l = 0.50 US$/l), the fuel economics would be somewhat lower, resulting in a price level of 3.89 US$/cylinder.

[4] This marks a fundamental difference with LPG / butane gas, which does liquefy at room temperature at moderate pressures (typically around 5 bar – depending on the ratio butane / propane in the LPG). A clear distinction should thus be made between these two products!

[5] Not to be confused with Liquified Natural Gas (LNG) which is cooled down to about -160 degC at which it liquifies under near atmospheric pressures.

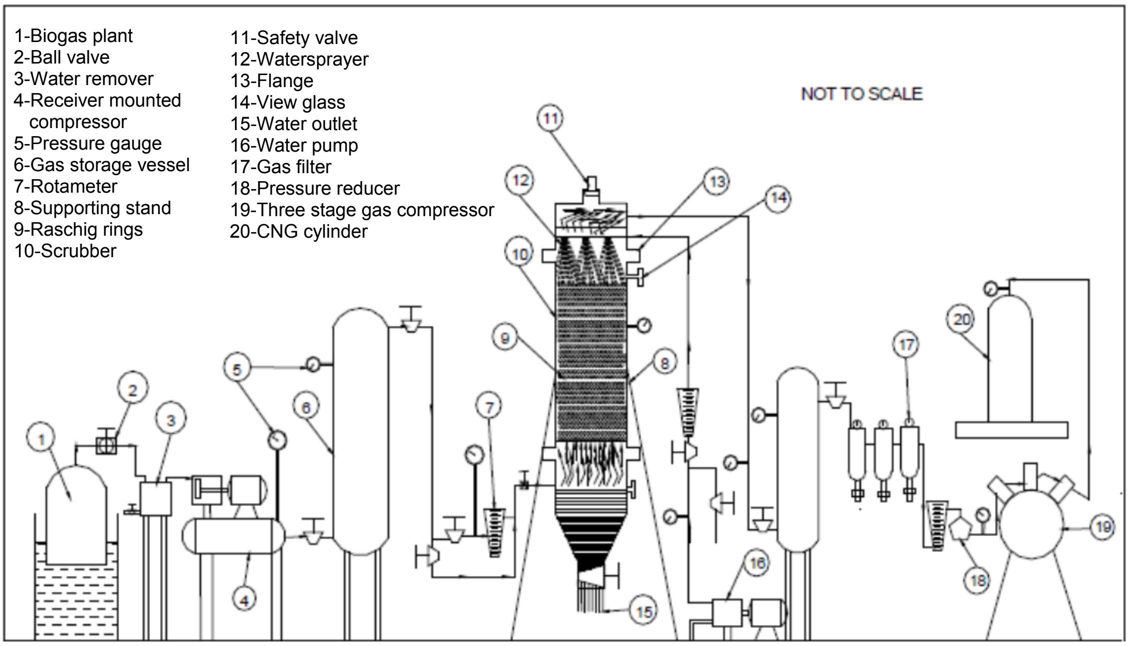

Figure 5: Biogas upgrading and bottling plant schematic. Source: Vijay (2009)

The economics are as shown in Table 1. Note that taxes have not been included. The figures show that total costs are approx. 70-140% above the potential level of income. In the household case it would be under the assumption that rural households would be willing and able to pay for a fuel that would be equivalent to LPG, which does not seem to be the case in the areas that were visited. In the case of the automotive uses, there would need to be a fleet of customers with modified cars to off-take the gas[6].

Table 1: Economics of biogas purification and bottling

	Unit	HH	Diesel	Gasoline	Remarks
Fuel Price	US$/unit	0.58	0.50	0.70	
Raw biogas equivalent	US$/$m^3$	0.25	0.27	0.35	
Price per 40l biomethane cylinder	US$/pc	3.61	3.89	5.16	
Annual turnover	US$/a	29,773	32,083	42,553	
Raw biogas processed	m^3/a	120,000			300 d/a, 8 h/d, 50 m^3/h
Investment costs	US$/a	150,000			Based on quotations for upgrading and bottles; estimates for pressurisation equipment and installation costs.
Capital costs	US$/a	35,380			Amortization and interest
Raw gas costs	US$/a	9,600			Alternative costs of 0.10 US$/kWh for electricity production (-/- generation costs)
O&M costs	US$/a	18,300			Energy, operator, maintenance
distribution and margin	US$/a	10,000			Lump sum
Total costs of distributed gas	US$/a	73,281			

Note that the economics are highly dependent on scale and fuel prices. A gasoline substitution project could be viable at e.g. a scale of 200 m^3/h and a gasoline price of 1 US$/l (4,000 KHR/l).

[6] One of the largest pig farm, BVB investments, has 4 vehicles consuming 1.5 t/month of diesel. The required gas for substituting this demand is approx 25% of what would be produced in the presented case. However, scaling down significantly affects the economics ot the operation.

Apart from the economic barrier, there is the safety issue. An Indian supplier of upgrading and bottling systems advised against the distribution of high pressure biogas in households as the risk of accidents when handling the cylinders are considerable (Garg, 2015).

Concluding: upgrading and bottling of biogas does not seem to be a viable option for household energy, because of the absence of market, the poor economics in comparison to alternatives, and safety issues. For automotive uses (replacement of gasoline) it could be viable for scales above 200 m^3/h and higher fuel prices (gasoline price of 4,000 KHR/l), but the absence of a client base would be a barrier to the development of such a project.

2.5 Market conditions for electricity in Cambodia

In general, the most profitable destination for electricity is to cover own demand. Particularly electricity produced with diesel generators is expensive; fuel costs alone are at least 0.20 US$/kWh but can be easily twice that amount where diesel prices are higher, and generators are running at lower efficiency. But also replacing grid supplied electricity with own production can be profitable; or at least more profitable than selling electricity.

Diesel prices in rural Cambodia (February 2016) have been found to range between 1,800-2,200 Riels/l (approx. 0.45-0.55 US$/l), with a most common found price of 2,000 Riels/l (0.50 KHR/l). The latter price has been used in this study. Note that these are so-called depot prices, at small franchise stations found outside larger towns and cities. In the large chain stations found in towns, prices are more commonly in the 2,800-3,200 KHR/l range (0.70-0.80 US$/l). The explanation of the difference must most likely be sought in the lower costs and lower margins of selling in rural areas.

In Cambodia, the electricity market is highly fragmented. In most parts of the country, electricity supply concessions are held by private suppliers (Rural Electricity Entrepreneurs - REEs), even though the national utility company EdC is rapidly expanding its transmission network. EdC itself holds the supply concession in parts of the country as well.

Originally, the REE’s produced most of the electricity themselves, using diesel generators or an occasional gasifier, and distributed this through their own isolated grid system. The Electricity Authority of Cambodia (EAC) set the sales price levels based on actual generation and distribution costs, including a margin allowing for repayment of investments. With the arrival of the EdC transmission grid in a concession area, EAC bases the prescribed rates on EdC bulk sales prices which is typically below the generation costs using diesel. REE’s then normally interconnect to the EdC network, buying electricity from EdC and reselling it to their customers. However, they are still free to obtain their electricity from other suppliers; several have indicated to be in principle interested in buying power from an IPP (i.e. a farm producing electricity from biogas) provided that the price is attractive, and power quality and reliability are good.

This situation does affect the original project premise of feeding mini-grids with biogas-based electricity. In the concession areas it is not permitted to supply electricity to other consumers; the possibilities of supplying to mini-grids are thus limited to connecting to local grids owned and operated by REEs or EdC, after negotiating about the price and supply conditions. This will result in a lower price level for the electricity; at the same time, (the cost of) managing the distribution system, and administering the electricity sales, can be left to the distribution company.

In only one case, the farm owner also holds the concession for supplying electricity in his area (see chapter 12). This affects the base price for the produced electricity as well as the supply conditions – all electricity can be absorbed by the grid, around the clock, throughout the year. The economics of this project are much better than other projects of the same scale and type.

An overview of EAC prescribed rates is included in annex 1.5. Wholesale prices from EdC to REEs depend on the point of supply: from MV substation the rate is 0.126 US$/kWh (2016-2020), from MV (sub)transmission line of EdC is 0.147 US$/kWh declining to 0.142 US$/kWh over the period 2016-2020.

Several REE's were contacted in the course of the study; all purchase electricity from EdC at the mentioned rates. All indicated to be interested in purchasing electricity if the price is reasonable, and the supply is reliable. One REE had experience buying from an IPP in the past, at a rate of 0.085 US$/kWh, but that supply was not stable. In the study, a rate of 0.10 US$/kWh is used in base case scenarios.

EdC indicated that they have a purchase agreement with a sugar factory (5MWe), buying at a rate of 0.09 US$/kWh. They indicated to the project team that they are in principle interested in buying electricity at MV level, for a price below 0.10 US$/kWh. However, they are only interested in buying electricity during dry season, when hydropower supply is lowest. In the study, a rate of 0.100 US$/kWh is used and a consumption of 50% of the excess electricity.

2.6 Slurry use

2.6.1 Nutrient contents

In principle, the anaerobic digestion of organic material does little to the (macro and micro) nutrients in the original material. Looking at nitrogen (N), phosphorous (P) and potassium (K), most is still present in the digestate, although small quantities of N can be converted to NH_3 in the biogas and a small loss of P can occur (Risberg, 2015). A remarkable difference is that part of the organic nitrogen (incorporated in the biomass) is converted to inorganic nitrogen (particularly NH_4 – ammonium). This is an advantage, as this is the part of nitrogen is immediately accessible to plants.

A review of several literature sources yield the following typical values of NPK in pig slurry (dung and urine combined):

- N: 10.2% of dry matter, of which approx. 70% inorganic
- P: 2.2% of dry matter
- K: 4.4% of dry matter

During the digestion process, dry matter is converted to biogas[7]. At a calculated biogas density of 1.03 kg/m^3, the conversion rate of 300 m^3 of biogas per tonne of DM suggests a removal of 31% of DM. For most of the farms, the DM content of the waste water is between 0.6-1.2%; that of the digestate will thus be between 0.4-0.8%[8]. Most of the farms looked at will produce between 250-1250 kg/d of DM in the digestate.

[7] Depending on the feedstock, small quantities of water are consumed in the process as well; these are not taken into consideration here

[8] Note that this is much lower than digestates from biogas systems operated on higher solids feedstocks. If a system is fed with a slurry containing 10% dry matter (e.g. 1 part fresh pig dung and 2 parts water), then dry matter content of the digestate is typically above 5%.

With the indicated DM reduction, and an assumed 10% reduction in P and N, the indicative values for NPK in the digestate will be:

- N: 13% of dry matter, of which approx. 80% inorganic
- P: 3% of dry matter
- K: 6% of dry matter

2.6.2 Fertiliser demand

According to Khy (2016), the most widely used fertilisers used by rice farmers are Urea (46-0-0), DAP (diammonium phosphate - 18-46-0) and NPK compound fertilisers (e.g. 20-20-18 and 20-20-13). Vuthy et al (2014) indicate that most fertilisers are used for rice production - particularly for wet season rice. Indicative application rates of (compound) fertilisers are as follows:

- 190 - 330 kg/ha for vegetables
- 180 - 240 kg/ha for dry season rice
- 80 - 150 kg/ha for wet season rice

In comparison, the dry matter in the digestate contains approx. half the nutrients of chemical fertilisers. The application rates would be twice the quantities above. However, the relative quantities of N, P and K required will depend on the soil type so that in most cases, a combination of organic and chemical fertilisers will be required in order to achieve the right balance of nutrients. Assuming 50% coverage by digestate, some 100-200 kg DM/ha of digestate could be applied on dry season rice land. On an average wet basis (0.6% DM), digestate application of approx. 15-30 m^3/ha of would be appropriate.

2.6.3 Application and valorisation of slurry

On the basis of price levels given by Vuthy et al (2014), present day price levels of chemical fertilisers are in the range of 40-50 US$ per 50 kg bag. This would mean that the replacement value of the digestate would be approx. 0.4-0.5 US$/kg. With the 0.6% DM of the digestate, the replacement value will be in the range of 2-3 US$/$m^3$ of digestate.

The main drawback of using digestate –in this case– is the low solids content. Straightforward techniques for separation of solids (decantation, filtration) are unfeasible because of the low solids content; other techniques (membranes, reverse osmosis, evaporation) are complex, capital intensive and energy intensive. At one farm, filtration of part of the digestate with a sand bed, and subsequent solar drying was applied; however, most of the nitrogen and all of the potassium will leach out and/or evaporate from the material during the process.

The remaining application method is in a liquid form. This is done on a small scale at some of the farms, e.g. for rice fields and fruit trees, using irrigation systems (canals) or tank trucks. This is technically well possible, but its range will be very limited, as transporting the liquid will be costly in comparison to its value. In addition, because of the large volumes, the liquid cannot be effectively stored for more than a few days or weeks. This means that the digestate can only be distributed when it is produced, which further limits the quantities that can be distributed.

Further complication, particularly in fattening farms where the “all-in, all-out” system is applied, is that the amount of solids varies widely throughout the year. As the water consumption varies less than the dung and urine production, in some months there will be digestate with (much) less solids, and in some months with (much) more solids. In other words, fertilising value will differ throughout the year.

Concluding, although the digestate represents a potentially valuable resource as a replacement of chemical fertiliser, the low (and in some cases varying) solids content will make it difficult to distribute substantial quantities. It is therefore not included as a potential source of income for the projects.

2.7 Greenhouse gas reduction

Looking at the greenhouse gas emission reduction potential of biogas projects in the piggery sector, broadly three mechanisms can be distinguished:

1. Avoidance of methane emissions from animal waste that is currently disposed of in ponds.
2. Avoidance of CO_2 emissions by replacing (fossil based) energy used on the farm with CO_2 emission neutral bioenergy.
3. Reduction of CO_2 emissions by replacing (partially fossil based) grid electricity that is presently consumed by the farm, or fed into the grid.

Methane emissions are calculated using the methodology presented in IPCC (2006), on the basis of the number of animals, the amount of volatile solids produced by each head, the methane emission per unit of volatile solids, and the assumed methane emission reduction achieved by improving the manure management system. Multiplication of the methane quantity with its global warming potential (25) results in the CO_2 (equivalent). For pigs, this is 426 kg CO_2eq/head/year; for cattle and chicken it is 1,175 kg CO_2eq/head/year and 0.5 kg CO_2eq/head/year, respectively.

CO_2 emission reduction from avoidance fossil fuel use is calculated on the basis of the number of litres of fuel replaced, the fuel density, net calorific value, and the CO_2 emission per unit of primary energy. For diesel, the CO_2 emission reduction is 2.68 kg CO_2eq/litre.

CO_2 emission reduction from grid electricity replacement is calculated on the basis of the quantity of grid electricity consumption avoided, the quantity of electricity supplied to the grid, and the grid emission factor for Cambodia. The CO_2 emission reduction is 0.66 kg CO_2eq/kWh (Kuriyama, 2015).

The potential emission reductions from each of the projects is indicated in the respective report sections; an overview of all projects is presented in the conclusions[9].

Note that the sales of carbon credits (CDM certified emission reductions or voluntary emission reductions) is increasingly difficult. The potential emission reductions from the combined projects have been discussed with representatives from a carbon financing specialist active in Cambodia (NEXUS, 2016). The scale of the cumulative greenhouse gas reduction (15,000-20,000 tCO_2eq/a) is small, although not too small. However, price levels are low (between 2-3 US$/t$CO_2$eq), and it is uncertain whether this is enough to recover recurring costs (verification)

[9] The values presented in this report differ slightly from those calculated in Leang (2016); these are due to the omission of emission reductions due to grid electricity consumption replacement and grid supply by the latter, and different interpretations of diesel consumption.

and project development costs. Over-all, the chances of successfully developing a carbon credit project component are deemed small, and potential revenue from carbon credit sales are not included in the further analyses.

2.8 Technology suppliers

Table 2 below shows a list of suppliers of (covered lagoon) biogas systems, biogas generators, gas treatment and monitoring equipment, and other equipment (grid synchronisation equipment, gas bottling) active in the region.

Table 2: Suppliers of other equipment

Company	Country	Description	Contact details	Digester	Generator	Gas treatment	Gas monitoring	Other
SOMA Energy Co Ltd	Cambodia	Constructed BAI biogas plant and biogas plant at slaughterhouse	Mr. Dana Leuk +855 23 722 215 +855 12 836 229 leukd@somaenergy.com.kh www.somaenergy.com.kh	X	X	X	X	
CP Cambodia	Cambodia	Supports biogas plant development; liaises with plant suppliers from Vietnam	Mr. NOUN Sophal +855 1282 0713 sophalnoun@gmail.com	X	X			
Smart Mekong Co Ltd	Cambodia	Installed large covered lagoon system at CKYE pig farm in Cambodia	+855 97 785 8191 smartmekong@yahoo.com	X				
Entech Associate Co., Ltd	Thailand	Gas analysers (distributer of Geotech Biogas 5000)	+66 2831 6666 info@entech.co.th www.entech.co.th				X	
Khai Biogas	Vietnam	Installed many covered lagoon systems in Vietnam; also active in Cambodia. Supplier of Caterpillar gas generators	Mr. Khai Tran +84 8 3889 1795 khai.apo@gmail.com http://apocorp.vn	X	X			
Lotus Green Technology Co., Ltd.	Vietnam	Gas analysers (distributer of Sewerin Multitec 540)	+84 8 3824 4597 +84 8 3823 7721 vuongnu.bui@lotus-greentech.com www.lotus-greentech.com				X	
Viet Huy Technical Scientific Equipment Co.	Vietnam	Gas analysers (distributer of Geotech Biogas 5000)	+84 8 3899 7325/26 info@viethuy.vn sales@viethuy.vn www.viethuy.vn				X	
Holly Enterprise Co Ltd	China	Biogas generators; gas treatment; Grid synchronisation equipment	Mr. Tonny Ma +86 10 5654 5378 +86 18 9420 50000 (m) hollyfoton@yahoo.com www.holly-foton.com		X	X		X

ETTES Power Machinery Co Ltd	China	Biogas generators (licensee of DEUTZ)	+86 13 6720 13688 +86 13 8213 32565 sales@ettespower.com ettespower@gmail.com http://ettespower.com		X			
Shenzhen Puxin Technology Co. Ltd	China	Small/medium biogas plants; small/medium biogas appliances; biogas treatment	Mr. Vane Yen +86 755 2893 8251 +86 134 2512 7057 (m) info1@puxintech.com www.puxintech.com			X		
Shenzhen Teenwin Environment Co.,Ltd	China	Small/medium biogas plants; small/medium biogas appliances; biogas treatment	Mr. Owen Chu +86 153 0264 8117 owen@teenwin.com			X		
Beijing SinCleanSky Technologies Corp	China	CNG cylinders (steel and carbon fibre)	Ms. Lynn Wang +86 10 8488 5229 +86 188 0110 0242 (m) lynn_wang@sinocleansky.com www.sinocleansky.com					X
Dalian Metery Technology Co., Ltd	China	Turbine gas flow meters	Ms. Amy Li +86 411 8684 8981 amy@metery.net www.metery.en.alibaba.com				X	
Aoxin Instrument	China	Vortex gas flow meters	Ms. Christina Liu +86 21 69172171 christina@aoxininstrument.com www.ochs.en.alibaba.com				X	
Green Brick Eco Solutions Pvt Ltd	India	Complete biogas plants; Landfill gas; Biogas analysers (distributer of Geotech Biogas 5000); Biogas upgrading and bottling	Mr. Sandeep Garg +91 11 4052 6992/93 +91 99 1118 9892 (m) sandeepgarg@gbes.in http://gbes.in	X	X	X	X	X
SIEMENS Systems House	India	Grid synchronisation equipment	Mr. Rakesh Yadav +91 731 2431 510/511 +91 942 5054 595 (m) support1@eaindia.co.in eaindore@eaindia.co.in					X
EngineTech Co Ltd	South Korea	Manufacturer of biogas generators	Mr. Dae Hyon Choi +82 31 369 0810 +82 10 3726 4964 (m) amigochoi@naver.com amigochoi@korengine.com www.korengine.com		X			

3 EXISTING BIOGAS PLANTS IN CAMBODIA

3.1 Battambang Agro Industry (BAI)

3.1.1 Company description

Battambang Agro Industry (BAI) is a cassava processing company in Battambang province, in the West of Cambodia. The processing factory was constructed in 2012 and started operating in October 2013. At full capacity, it produces cassava starch (300 t/d) and sun dried cassava chips (150 t/d); intake is then 1500 t/d of fresh cassava root. The company doesn't grow cassava itself; all roots are purchased from farmers in the region. The factory operates when there is fresh cassava root available, which is 4-6 months per year.

Figure 6: Overview of Battambang Agro Industry (BAI)

The cassava starch production process entails roughly the following steps:

- Removal of tails from the roots (manually)
- Washing and peeling of the roots
- Sorting and removal of irregularities (manually)
- Root rasping
- Separation of cassava (milk) and fibre
- Separation of water from the cassava milk
- Drying of the cassava cake (thermal)
- Starch sifting and packaging

The factory also has its own laboratory for monitoring the quality of the final products.

Figure 7: Separator centrifuge

Figure 8: Storage of final product

There are three main sources of waste:

- Waste water from the washing of the roots. Quantity is unknown, but is has a modest chemical oxygen demand (COD) - less than 500 mg/l.
- Waste water separated from the cassava milk; this is some 3,000-4,000 m^3/d when the plant is running at full capacity. COD of this waste water varies, but is on average around 18,000-19,000 mg/l.
- Fibre from the cassava root. This is some 450 t/d (wet) at full capacity. Lab tests show that the material contains some 81% water, and 45% of the dry matter is starch and 2% is inorganic matter (ash).

The company is situated on the MV grid. There are four transformers: for the factory, the office, the water treatment plant and the biogas plant. Total electricity consumption in December was approx. 1,127 MWh; that month there were approx. 20 days of full production so daily electricity consumption is estimated at 55,000 kWh/d. Peak load in December was 2.76 MW; the company uses power factor correction so the peak apparent power will be below 3 MVA.

3.1.2 Biogas plant

The company uses an Anaerobic Baffle Reactor (ABR) of 41,000 m^3 for the treatment of their wastewater. It consists of a large covered lagoon where the wastewater passes through a series of sludge beds that a separated by baffles. The anaerobic bacteria reside in the sludge; because of the low speed of the water passing through, the sludge remains inside the reactor, and the bacteria convert the solids in the waste water into biogas.

Because of the fluctuations in the COD of the fresh waste water from the factory, the waste water first flow into a storage pond where it mixes with the waste water from previous days. In this pond first decomposition takes place, resulting in a drop in pH and a reduction of COD. From the storage pond, the waste is pumped into a mixing pond next to the ABR; here the water is mixed with cleaned water from the ABR in a ratio of approx. 1:1.5, neutralized with Sodium hydroxide, and subsequently pumped into the ABR.

Figure 9: BAI biogas plant

Figure 10: Mixing pond

The biogas is captured and stored under the cover; according to the manager, gas storage volume is 6,000 m^3 but seen the size of the plant this might be significantly higher. The gas is dewatered with a cooling unit, pressurized with a blower (approx. 200 mbar), metered, and sent to the factory for heat production or to a flare in case of excess. Gas production and quality is monitored in-line.

Figure 11: BAI thermal oil heater

Figure 12: BAI flare

3.1.3 Plant performance

The performance of the plant seems to be good. Gas quality is good: spot measurement of raw biogas showed 67% CH_4, 28% CO_2 and some 400 ppm H_2S. In previous years, factory production was limited and erratic; the biogas plant did not produce sufficient gas to produce all the required heat for the factory so that heavy fuel oil needed to be co-combusted in the heating system. Starting the campaign in November 2015, the factory operates at a higher level, and more continuously. The biogas plant started up quickly and produces more gas; for the first time there has been excess gas that needs to be flared.

For the period 7-24 December 2015 the production data were as follows[10]:

- The factory operated for approx. 14 full days in the 18 day period (80% average capacity).
- System inflow approx. 2,800 m^3/d with an average COD of approx. 13,100 mg/l.
- Average COD of outflowing water was approx. 1,100 mg/l.

[10] Data from later months (January/February 2016) are available but are based on estimates as the central monitoring system broke down early 2016.

- Average biogas production was approx. 13,300 m^3/d; approx. 6% of this was flared. At 100% factory production, gas production would be approx. 16,800 m^3/d.
- Gas production per kg of COD removed was approx. 0.36 m^3/kg; methane production would be 0.25 m^3/kg COD removed[11].

3.1.4 Potential improvements

There are in potential three avenues for increasing the energy supply to the BAI Company: Increasing the gas production of the current biogas system, utilisation of excess biogas, and/or utilisation of the fibre. Note that company management is already in the process of investigating the latter two options.

Increase in ABR gas production

The biogas production of the ABR is what can be expected on the basis if the waste water from the wastewater storage pond. As the waste water in the storage pond is a mixture of waste water from several (3-4) days, extremes in COD values are evened out. However, as COD analyses of both the fresh waste water and that from the storage pond indicate, the intermediate storage already results in a reduction of COD of about 30%. This would mean that the biogas potential of the fresh waste water is actually higher than that of the waste water after storage.

In potential, increases in biogas production upto 30% could be obtained by omitting the intermediate storage – partially or completely – and using the raw waste water coming from the separator. It may require mixing with larger quantities of ABR effluent, in order to reduce the COD level of the water going into the ABR, and/or varying the ratio of raw waste water to ABR effluent in order to reduce COD peaks. Both options could be experimented with, monitoring the ABR performance (gas production; stability of effluent COD; VFA).

An additional advantage could be that less NaOH would be required for correcting the pH of the water, as the fresh waste water is substantially less acidic than the water coming from the storage lagoon.

Utilisation of excess biogas

As of December 2015, biogas production is somewhat higher than biogas demand in the factory, and on some days excess biogas is being flared. Company management is considering the installation of a generator set that could convert the excess biogas to electricity.

In recent months, average excess biogas amounted to approx. 500-1000m^3/d; it is expected that when starch production will increase further, additional excess biogas can be expected. It is advised to continue monitoring as soon as the monitoring system has been repaired. Also, the volume of the gas storage should be verified, as this should allow peaks and lows in gas production to be evened out so that a more constant amount of gas would be available for electricity production.

In the meantime, on the basis of an estimated 3,000 m^3/d of excess biogas, daily electricity production of some 6,500kWh/d can be expected (approx. 12% of the total company electricity demand at full load). If this would be used continuously for 24 hours per day, and the generator would be run at 90% of its rated capacity, a unit of approx. 400 kVA would be

[11] The theoretical maximum methane production would be 0.35 m^3/kg COD removed

required. The generator could be synchronised with the grid supply at the factory level, and as such replace part of the electricity that would otherwise have been supplied by the grid.

A first-order economic assessment shows the following:

- Investment costs including hardware (generator, desulphurisation, synchronisation) and its installation would be in the order of 250,000 US$.
- Annual costs for operation and maintenance would be in the order of 5% of investment costs, i.e. 12,500 US$/a.
- Annual savings, assuming 120 days/a and 18 h/d operation and the indicated electricity rate of 0.186 US$/kWh, would be 111,000 US$/a.
- Simple payback period would be 2-3 years.

It is advisable to consider this option within the context of other energy supply options. An increase of ABR output (see above) would increase excess biogas, requiring a large generator. The combination of a small project and a larger project (see below) would be less economical than only the larger project that would integrate also the existing biogas production. On the other hand, a smaller project would allow the company to familiarise itself with electricity production at a smaller scale.

Utilisation of fibre

As indicated in section 3.1.1 above, the company produces large quantities of wet fibre, which contains much water but also much starch. Two options for converting this material into energy are being considered:

1. Using the fibre for biogas production, in a stirred reactor. The starch would be converted to biogas (methane content around 50%[12]) and the fibre would remain. This gas-and the excess of the existing biogas system – could be used for electricity production; first calculations indicate that this option could cover the full electricity demand of the company, also during full-load operation.
2. Using the fibre for heat production in a solid fuel combustion system (after mechanical dewatering); there is about 3 times more fibre than which is needed to cover the heat demand. This would then liberate the full amount of biogas that is now being used for heat production, and make it available for electricity production. This option could cover some 70% of the electricity demand of the company.

Further technical and financial assessments are being carried out. A main constraint for any of the options is the relatively short operating period of the starch plant (4-6 months per year) results in sub-optimal utilisation rates of any of the systems (including also the excess biogas utilisation option described above).

3.2 Sim Chanrith Farm

3.2.1 Plant description

The farm of Mr. Sim Chanrith is located in Kampong Chhnang province, some 20 km south of the province capital Krong Kampong Chhnang. It is a breeding farm, holding on average 780

[12] Mixing of the biogas from the ABR might be required to increase the methane levels to 55-60% for trouble-free use in gas engines

sows in two (closed) farm buildings. The average piglet production is 1,050 heads per month which are sold at a weight of approx. 5kg.

Dung production by the sows and piglets is estimated at 1.2 tonnes per day. On the basis of operator indications and own flow measurements, water consumption for cleaning was estimated at 25 m^3/d. Total waste water production, including urine and water evaporation, is estimated at 26 m^3/d.

Figure 13: Overview of Sim Chanrith breeding farm

The farm has a small HDPE covered lagoon biogas system, installed 3 years ago by a Vietnamese supplier. The volume of the system is approx. 1,800 m^3 (WxLxD = 25x30x3m), resulting in a retention time of 69 days. The material flows are as follows:

- Cleaning of the stables start with removing the solid dung (approx. 800kg/d).
- Waste water from hosing the two buildings flows into a settling pond; from there it is pumped into a mixing pit.
- Inside the mixing pit, the solid dung is mixed with the waste water; from there it flows into the digester.
- Twice per month, part of the digester contents are pumped out, and deposited on sand bed for separating some of the solids from the slurry. These are dried and used as fertilisers around the farm, and sometimes sold to neighbouring farmers.

Figure 14: Sim Chanrith biogas plant

Figure 15: Sim Chanrith generator set

There is no gas treatment; gas composition was CH_4 67%, CO_2 30% and H_2S 750ppm. The biogas is piped directly to a generator room where it is used for dual fuelling two diesel generators that are running in turn to produce electricity (24/7). Both generators consist of a 4-cylinder car engine (estimated 50hp) driving a 22kVA alternator. Both gas supply and diesel supply are regulated manually, resulting in electricity frequency variations between 38-50 Hz.

3.2.2 Biogas system performance

Before the visit, the farm owner had indicated that his system isn't function at the desired level: diesel consumption is reduced by 30-40% whereas on the basis of potential fuel replacement in duel fuel systems he had expected higher fuel replacement.

Biogas production potential

On the basis of the number of animals, average biogas production is estimated at 120 m^3/d. because of fluctuations in the number of animals, production will vary between 100-140 m^3/d. The retention time of the waste water is approx. 70 days which is more than long enough for complete digestion.

Energy demand

On the basis of used equipment and measurements with a power logger, the total electricity demand at the farm is estimated at approx. 310 kWh/d:

- There are on average 110 incandescent light bulbs (100W) burning 24/7, for warming of the piglet stables (11 kW, 264 kWh/d).
- Three pumps (0.75 kW each) are used for pumping and pressurizing washing water; total consumption is approx. 10 kWh/d.
- Three pumps (0.33 kW each, automatically regulated) are used for pumping drinking water, plus a pump for getting the water in an elevated reservoir; total consumption is estimated at approx. 10 kWh/d.
- Various other small pumps used irregularly for slurry pumping (2), water curtains (2), disinfectant pumping (2), kitchen and household water pumping. Total average consumption estimated at 10 kWh/d.
- Lighting during night-time (18h-6h) concerns 45 CFL of 18W each (0.8 kW, 10 kWh/d)
- There are 2 refrigerators, consumption estimated at 5 kWh/d.

Average load is approx. 13 kW which means that the average engine loading rate is approx. 35%. The total diesel consumption at the farm is 90 l/d when biogas is used, and 135 l/d when there is no gas. Of this quantity, some 20 l/d is used for driving the fans in the closed stables. Consumption of the generators without biogas is thus 115 l/d, around 2.7 kWh/l diesel. Seen the capacity and loading rate of the diesel engines, this can be considered normal consumption.

The 120 m^3/d of biogas reduces the diesel consumption with 45 l/d, which results in a replacement rate of 0.38 l diesel per m^3 of gas. Seen the high methane level in the biogas this is on the low side but not unexpectedly low. Taking the diesel consumption of the fans out of the equation, the gas reduces the diesel consumption of the genets from 115 l/d to 70 l/d, which is a reduction of some 40%. This is in accordance with the farm owner's indication; however, the level of replacement is in this case limited by the available biogas, which is in turn limited by the number of animals kept on the farm. This is also supported by the observation that there was no gas under the cover on either day of the farm visit, indicating that there is no overproduction of biogas.

Note that the engine operator indicated that an increased gas supply leads to engine knocking and heating up. However it is unknown at which gas supply rate this occurs as there is no gas meter or diesel consumption meter to determine the instantaneous ratio of fuels.

3.2.3 Suggestions for improvement

Although the over-all biogas system seems to work as can be expected, there are several potential options for improvement.

1. Gas treatment.

Every year, one of the engines needs to be replaced at a cost of 5,000 US$ (3,000 US$ for the engine plus 2,000 US$ for installation). It might be possible to reduce this frequency if measures were taken to reduce H_2S in the gas as this leads to rapid engine deterioration. As the gas consumption rate (around 5m^3/h) is limited, a relatively straightforward system with iron oxide pellets could suffice. Such systems can be bought from Chinese suppliers or could be manufactured locally.

The basic economics of such a system would be as follows:

- Initial investment costs in desulphurisation system from China (10 year lifetime): 3,000 USD
- Annual operation and maintenance costs are estimated at 5% of the investment costs (eventual replacement of the iron oxide pellets) or 150 USD/a
- Annual cost savings: if engine lifetime is increased with 1 year (from 2 to 3 years), average cost savings would be 1,666 USD/a. If engine lifetime is increased with 2 years (from 2 to 4 years), average cost savings would be 2,500 USD/a.
- Simple payback period would be 2 years with 1 year engine life increase, and 1.3 years with 2 year engine life increase.

2. Monitoring.

There are no systems for monitoring gas production/consumption and electricity production, which makes it impossible to assess digester and generator performance. For a few hundred dollars, a diaphragm meter and a kWh counter could be installed.

3. Increased gas production.

The volume of the biogas system is relatively large, seen the quantity of waste water. It should be possible to increase gas production by adding co-substrates, e.g. from agro-processing. On the basis of gas production rate of feedstocks, the diesel replacement rate, and the diesel price, a maximum cost level of such feedstocks can be calculated[13].

4. Speed regulation.

Although it does not directly affect energy consumption or production, the low engine speed and the resulting low frequency are a form of poor power quality. It is advisable to have a speed governor installed that keeps the engine speed constant by regulating the diesel consumption; it will automatically adjust the diesel consumption if biogas is added to the combustion air.

3.3 Mong Reththy Farm

3.3.1 Plant description

The pig farm of Mong Reththy Group is one of the country's largest. It is a mixed farm, with approx. 2,500 sows and 30,000 fattening pigs. The farm is expanding the number of fattening pigs to 40,000; this will take place in the first half of 2016.

On the basis of the current number of pigs, total daily dung production is estimated at approx. 25 t/d. According to farm management, water consumption is most likely higher than that at smaller farms as they run a very clean farm and thus consume relatively much water. Assuming an average water consumption of 40 l/head/d, total waste water production (including urine) would be approx. 1,300 m^3/d.

Figure 16: Overview of Mong Reththy farm

[13] For example: at a diesel price of 0.50 USD/l and a conversion rate of 0.57 litres of diesel per m^3 methane, the value of methane would be approx 0.28 USD/m^3. A starch-based co-substrate (e.g. broken rice), producing some 0.35 m^3 methane/kg, could then be added if the price is below 100 USD/t. Fresh solid pig dung (32% dry matter, methane production 0.2 m^3/kg DM) could be added at price levels below 18 USD/t.

All the waste water is treated anaerobically. There are 4 biogas units with a combined volume of approx. 76,000m^3 (three units of 17,000m^3 and one of 24,000 m^3), with gas storage of 44,000 m^3. The units are connected as pairs in series: the waste water is divided over two of the digesters, and subsequently flows from each digester into a second unit. The total average retention time is approx. 58 days, or which some 32 days in the first digesters. As can be expected, the bulk of the biogas is produced in the first digester units. After digestion, the digestate flows into a large pond where it remains.

The system was installed 3 years ago, designed and partially constructed by the company, only Thai and Vietnamese suppliers were contracted for doing all the sheeting work.

Figure 17: Covered lagoon digesters

Figure 18: Gas treatment system

All the gas is used for electricity production, for covering the farm needs and for sales to the community during night-time. There are in total 4 generators:

- 2 identical Yanmar units (1.25MVA). These were originally intended for use with LPG but were modified to run on biogas. Gas / air mixing of all sets is done manually. Derating is estimated at 20-30%.
- 1 Mitsubishi unit (1.25MVA). This unit is also converted from LPG to biogas, but is currently not working properly. A similar unit was previously used but was damaged and then decommissioned after one year.
- 1 backup diesel unit (1.25MVA). It used to run in dual fuel but this was stopped in order to reduce risk of downtime.

Normally, the two largest sets are used intermittently, each unit running for several weeks at a time. During daytime, only the farm is supplied by the generators; during night-time, supply to communities in the area are added to this. The farm is also connected to the EDC grid, which is used for distributing electricity during daytime when off-farm load is too high to be supplied by the gas generators. EDC grid also serves as a first backup, in case there is a problem with the generators or the biogas runs out.

There is a gas filter installed but it only contains crude fabric which is washed out with water from time to time. There are several scrubbers but these are not used as their capacity was found to be insufficient.

Figure 19: Gas generator 1.25 MVA

Figure 20: Gas mixing

3.3.2 Plant performance

Over-all, the biogas plant seems to perform well. The digester units are big enough to ensure near optimal biogas production, and will also be big enough to treat the additional waste water that will be produced after the farm capacity extension. On the basis of the current number of animals, gas production is estimated at some 3,100 m^3/d. With the additional waste water this could increase to 4,000 m^3/d.

Company records indicated that production of the gas generators during the period mid-December 2015 to mid-January 2016 was on average approx. 6,400 kWh/d. This is in line with what can be expected from the quantity and quality of the biogas.

During the visit, spot measurements showed 330-350 kWe load at 0.90 power factor. This was confirmed by load measurements during night-time with a power logger. According to the biogas plant manager, village load during night-time is max 150 kVA. This means that the generators are operator above 50% of their (derated) capacity.

The gas filtering system does not effectively remove any H_2S or water vapour, which was verified by gas measurements before and after the filter. The raw biogas contained 67% CH_4, 31% CO_2, and 450 ppm H_2S; the gas after the filter contained 66% CH_4, 31% CO_2, and 430 ppm H_2S.

3.3.3 Suggestions for improvement

Although the biogas system and the power plant seem to operate according to expectations, the following improvements could be taken into consideration:

- ***Gas treatment.*** Especially H_2S reduction should be implemented in order to prolong the lifetime of the generators. This could be done with air injection into the digester gas storage, water scrubbing, and / or by passing the gas through ferrous oxide. Such systems can be purchased in China or constructed by biogas plant technicians. Effectiveness of the H_2S removal should be monitored with gas analysis equipment. Investment costs are estimated at 20,000 USD. Assuming an expected life span of the two engines without gas treatment of 4 years and 8 years with gas treatment, replacement cost savings would be approx. 25,000 USD/a, i.e. 0.8 years simple payback period.
- ***Gas quality and quantity monitoring.*** Measuring the gas production of the plant / consumption by the generators (gas flow meter), as well as gas quality (CH_4, CO_2, H_2S),

could help determining the generator efficiency and finding the air-gas mixture giving the highest efficiency. It could also help determining the effectiveness of gas treatment, and provide insight in the functioning of the biogas plant.

- ***Gas-to-air mixture regulation.*** Gas mixing is now done manually; it is advised to determine whether this is actually affecting system output, i.e. to monitor gas quality and generator performance over an extended period of time. If an automated system is to be preferred, a lambda control unit could be considered, regulating this ratio on the basis of measured oxygen levels in the exhaust gas.
- ***Generator load optimization.*** At the moment, the generators supply the farm, and also nearby communities during night-time. This means that the generator loading rate is determined by these loads; possibly a higher efficiency could be obtained by (continuously) running the generator load at a higher output level. Also, it is possible that in the near future, when gas production increases, some of the gas cannot be used as existing loads are limited. Both problems could be resolved if the generators could (also) supply electricity to the communities in the area during daytime. This could be done by synchronizing the generator to the EDC grid, and run it at a higher rate (e.g. 600-700 kW). This would then mean maximum conversion efficiency and ensures that also in the future, all biogas can be converted to electricity. Synchronisation equipment can be obtained from suppliers in China.
- ***Waste heat utilisation.*** Most farms – particularly breeding farms – use heat for keeping warm the piglets. This is typically done with electricity, e.g. using incandescent light bulbs. As there is generator waste heat available 24/7, it may be interesting to use part of this heat to substitute the electricity consumption if the investment in the required infrastructure (insulated hot water piping and convection heaters) would weigh up to the savings in electricity. A quick pre-feasibility study could be carried out in order to determine the basic economics of such a project.

3.4 Kuch Sokha Farm

3.4.1 Plant description

The farm of Mr. Kuch Sokha is located in Kandal province, some 20 km to the north-east of Phnom Penh. It is a fattening farm working under contract with C.P. Cambodia, with an “all-in, all-out” system. It started 5 years ago and now has 7,000 fattening pigs in 8 stables of different sizes. At present, three of the stables are of the closed type, fitted with mechanical ventilation and water curtains. It is the intention to apply this to the other stables as well.

Figure 21: Overview of Kuch Sokha Farm

The farm has a biogas plant that was constructed late 2015, and started up early 2016. The size of the plant is 37x77x7m (approx. 15,000m^3), with an estimated 5,000 m^3 gas storage. The waste water from all the stables flows to two collection pits, and flows from there into the digester unit. The plant was installed with support from C.P., in the form of technical advice and supplier selection (Vietnamese). The investment (approx. 50,000 US$) was done by the farm owner himself.

At the time of the farm visit (February 2016), no generator had been installed. The farm owner also has a farm in Kampong Speu, with a biogas unit. They have had constant problems with the gas engines (breakdowns) so they are hesitant where it comes to investing in an expensive generator set. They have no gas treatment of any kind, which may be the root of the problems.

3.4.2 Plant performance

As the biogas plant has been started up only recently, with no use of the gas, no much can be said about its performance. At the time of the visit, the gas storage was only approx. 25% filled, which could be expected as the farm had just received new piglets and the dung production at the farm had not yet reached high levels.

In terms of ***dung and total waste production***, the following can be said:

- On the basis of the number of pigs, average dung production is estimated at approx. 5.5 t/d. because of the all-in, all-out system, this will vary between 0 and 11 t/d. Urine production will vary between 17.5 and 35 m^3/d.
- Water consumption for changing baths and stable cleaning varies throughout the fattening cycle. For piglets (0-2 months), bath water is changed twice per day; after that only once per day. Hosing is done on a daily basis during the last month only; before then

it is done on an irregular basis (estimated average twice per week). Total water consumption will be between 180 and 280 m^3/d, on average approx. 230 m^3/d.

- Total waste water production is estimated at 250 m^3/d on average, varying between 200 and 285 m^3/d. This is on average 36 l/head/d, which is below the average found in the sector (43 l/head/d). Total solids will be on average 0.8%, varying between 0-1.5%.

Figure 22: Kuch Sokha covered lagoon digester

Figure 23: Pig slurry pit

On ***biogas and electricity production potential***, the following can be said:

- Biogas production potential is estimated at 630 m^3/d. Similar to dung production, there will be a large variation in this, between 0 and 1260 m^3/d.
- On the basis of an electricity conversion rate 1.9 kWh/m^3 of gas, electricity production potential will vary between 0 and 2,394 kWh/d, with an average of 1,197 kWh/d. Assuming 90% generator availability, annual production potential will be approx. 393,000 kWh/a.

On ***farm energy demand***, the following can be said:

- The farm is connected to the grid of a local REE; electricity consumption is approx. 2500 kWh/month (80 kWh/d; electricity price is 0.26 US$/kWh). This is mainly for water pumping: there are 10 x 1.5 hp pumps that are automatically switched. There is minor load for lighting and pressure pumps for cleaning (3hp, in each stable), estimated consumption 10 kWh/d. Peak load will be approx. 20 kVA.
- In addition, in every cycle there are 10 to 20 days (hot / cold season) where the farm uses incandescent lamps (132 x 250W = 33kW = 400kWh/d) for warming the piglets during night-time. Peak load will be 33 kVA, on top of (part of) the water pumping load.
- As the farm is gradually switching to closed stables, future consumption and load will increase. Each stable has 4-8 fans of 1.5hp and two 1.5hp pumps for the water curtain which are automatically switched. Estimated electricity use is 40 kWh/d for each stable with an estimated average peak load of 10 kVA/stable. The three stables that are currently closed are powered by a 200 kVA diesel generator.
- Total (future) consumption is estimated at approx. 150,000 kWh/a. The load will vary throughout the day: In the morning it will be mainly water pumps (approx. 20 kVA), during the day it will be the fans and water curtains in the closed stables, with some water pumps for drinking water (approx. 80 kVA max). When the incandescent lamps are used, night-time load will be approx. 40 kVA max.

The preliminary ***over-all conclusions*** on the system are the following:

- The biogas system size and the maximum waste production rate indicate a minimum retention time of 52 days, which is more than sufficient for maximum biogas production.
- The average electricity production potential is more than enough to cover the full energy demand of the farm. However, because of gas production fluctuations, there will be months where there is no gas available, and months where there is a large quantity of excess gas.
- On the basis of preliminary assessments, the maximum farm load is expected to be some 80 kVA. In order to convert all biogas to electricity, a genset of approx. 160 kW (200kVA) would be required.

The basic economics of both cases are shown in the table below:

Table 3: basic economics of electricity production systems

Case	Captive use	Grid supply
Generator capacity (kVA)	100	200
Total annual electricity production (kWh/a)	135,604	393,215
Grid supply (kWh/a)	0	257,610
Investment costs (USD)	46,200	72,600
Generator (USD)	*28,000*	*43,000*
Gas treatment (USD)	*6,000*	*9,000*
Electrical systems (USD)	*0*	*6,000*
Structures (USD)	*5,000*	*5,000*
Engineering and installation (USD)	*3,000*	*3,000*
Contingencies 10% (USD)	*4,200*	*6,600*
Annual O&M costs	4,100	5,870
Annual income / cost savings	35,257	61,018
Simple payback period	1.5	1.3

On the basis of (expected) grid electricity savings, the annual savings would be approx. 35,000 US$ (based on 90% replacement). If the excess electricity could be sold to the grid, at a rate of 0.10 US$/kWh, this would yield another 26,000 US$/a. The latter option has a lower payback period.

Note that the payback periods shown in the table cannot be directly compared to those of other projects presented in this report, as the investment costs and operating costs of the biogas unit has not been included.

The local REE (Mrs. Chup Neang, tel 0978511151 / 012698050) was already contacted by UNIDO and indicated to be potentially interested if the price and conditions were attractive.

3.4.3 Suggestions for further steps

With the digester having been installed, the installation of a generator set should be considered as the next main step. On the basis of the above assessments, the following suggestions are made:

- A decision will need to be made whether a genset should be installed for covering the farm electricity needs only (approx. 100 kVA), or for converting all available biogas (approx. 200 kVA). It is advised to 1) verify the peak loads of the existing closed stables and of the water pumping system, so that a proper capacity generator set can be selected; 2) contact the local REE to further discuss supply rates and conditions.

- In case a choice is made for a smaller generator, for the farm only, possibilities for reducing peak loads should be considered. For example, with larger water storage, water pumping could possibly be limited to the hours where the closed stable ventilation and cooling are operating, i.e. during morning and late afternoon / early evening. Also, the generator should only be run when there are high loads; small loads (e.g. for CFL lighting, or small pumping loads) could best be covered by grid electricity, as extending generator operating hours will eventually lead to a shorter lifetime.
- In any case, a system for the removal of H_2S should be installed, in order to extend the lifetime of the generator. This could be a combination of biological removal (air injection into the digester gas storage) and chemical removal (passing the gas through iron oxide pellets). This is also recommended for the owner’s other farm in Kampong Speu.

4 FEASIBILITY STUDY: SAR RATHA

Table 4: Sar Ratha farm location and contact

Farm	Sar Ratha
Village	Phum Thmei
Commune	Takream
District	Banuan
Province	Battambang
GPS	13.0747N, 103.0226E
Owner	Mr. Sar Ratha
	088 894 8031

4.1 Introduction

The farm of Mr. Sar Ratha is located in Battambang province, in the West of Cambodia. It is a mixed farm, featuring both pig breeding and pig fattening; the average number of animals is approx. 1500 heads. In addition, the farm holds cattle, goat, sheep, chicken and ducks. The numbers of animals and the variation therein are shown in Table 5 below.

Figure 24: Map of Sar Ratha farm

The farm has a total of 12 stables on a land area of 100ha: 8 for pigs, 2 for chicken, and 2 for cattle of which one in another location. The stables are placed at a distance of approx. 100-200m from each other (see map in Figure 24, showing the 8 pig stables and one of the cattle stables).

In addition to the farm, the owner owns a rice mill, located on the main road through the village, approx. 2km from the farm. The mill is operated throughout the year, although the operating hours and days depend on the demand for rice. Annual production is some 2000 tonnes of paddy, most of which is from the owner's stock.

4.2 Farm operation

The farm breeds its own pigs for fattening: production of piglets is about 200-300 per month. Fattening is done in a period of 4-5 months, depending on the meat price around the time of finishing. During this period the animals are raised from a weight of approx. 15kg to 120 kg per head.

Total feed consumption on the farm is 3-4 t/day; pigs produce on average 1 kg meat on 2.3 kg feed. Pigs and chicken are fed with broken rice from the owner's own mill, when rice prices are low. In addition, some 17-20% of crude protein is added to the pig feed. When rice prices are high, the owner buys prepared feed from CP or BetaGro.

Pig dung is removed with water, and ends up in ponds located behind each stable. The owner used to apply the slurry in fish ponds. However, the last dry season was long and the dung ponds dried up (Jan-Aug); the dried dung could then be sold for 2500 KHR/bag (@40 kg/bag).

4.3 Biogas feedstock

4.3.1 Manure and urine production

Table 5 below gives an overview of the number of animals, the variation therein, as well as the recoverable daily dung.

Table 5: Average livestock and recoverable dung and urine production at Sar Ratha farm

Animal	Heads	Variation	Fresh dung (t/d)	Urine (m^3/d)	Total DM (t/d)
Fattening pigs	1300	±30%	1.02	3.25	0.39
Sows	180	±10%	0.28	0.90	0.11
Boar	12	N/A	0.02	0.04	0.01
Cattle	180	N/A	1.08	N/A	0.22
Goat and sheep	87	N/A	0.00	N/A	0.00
Chicken	20,000	Large	0.40	N/A	0.10
Ducks	4,000	Large	0.00	N/A	0.00
Total			**2.79**	**4.19**	**0.82**

Note that dung from chicken and ducks contain high levels of nitrogen (C:N ratio generally below 10). As the nitrogen level of the pig dung is relatively high in nitrogen as well, adding chicken dung would bring the C:N levels down further which may eventually inhibit the digestion process. Also, the bedding material (rice husk) mixed with the dung will decompose only very slowly, which may cause a build-up inside the digester if added in too large quantities. It is therefore advised to use only moderate quantities of the chicken dung, unless in combination with other substrates with high C:N to compensate. Adding a quantity of 25% of the available amount is considered safe; higher amounts can be experimented with in the future.

Cattle dung may be an interesting substrate to add to the mixture. It typically has a C:N ratio in the range of 20-30 which is favourable for anaerobic digestion. It is relatively dry (around 15-20% DM when fresh) so it will add little to the total volume of waste. The recoverable quantity will be limited as the animals are kept in the kraal only during night time. A recovery rate of 40% is estimated, because of daytime roaming and the two different locations.

Goat and sheep are also grazing most of the time; the recoverable quantity of dung is negligible.

Animal dung is generally sold as fertiliser:

- Pig dung: during dry periods, dry dung can be recovered and sold in 40kg bags at approx. 15 US$/t (dry).
- Chicken: mixed with bedding material is sold in 30kg bags for approx. 25 US$/t (dry).
- Cattle dung: sold in 40 kg bags for approx. 20 US$/t (dry).

Note that the availability of dry pig dung for sales is sporadic. For the chicken and cattle dung, the value of the material for biogas production is 2-6 times higher than above sales price, depending on the use of the energy (own use or grid supply).

Average urine production is estimated at 4.2 m^3/d, varying between 3.0 and 5.5 m^3/d.

Figure 25: Stable at Sar Ratha farm

Figure 26: Facility for waste water removal

4.3.2 Water consumption

On the farm, most of the stables have their own (mostly diesel driven) water pump, pumping ground water for drinking and (especially) stable cleaning. Water flow measurements showed flows of 30, 90, 100 and 150 l/min. According to the operator, stable cleaning takes approx. 1.5 hours during which water is fully used, so water consumption per stable is on average 9m^3/d. Total water consumption is thus 72 m^3/d (48 l/head/day).

Water evaporation during cleaning and bathing is estimated at 0.5 m^3/d/stable or 4m^3/d.

4.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 6 below. Waste production (50 l/head/day) is significantly above the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d). A reduction in water consumption (e.g. by closing off water when not in use, or using pressurized water for hosing) would reduce the biogas system volume, and the energy consumption of water pumps.

Table 6: Total waste production at Sar Ratha farm

Source	Unit	average	minimum	maximum
Water	t/d	72	72	72
Dung (fresh)	t/d	2.8	2.5	3.1
Urine	t/d	4.2	2.9	5.4
Evaporation	t/d	4.0	4.0	4.0
Total waste water	t/d	75	73	77
DM content	%	1.1%	0.9%	1.2%

4.3.4 Biogas and electricity production potential

Table 7 below gives an overview of the biogas and electricity production potentials of the different sources of dung, as well as the variation therein. Biogas production is based on 300, 250 and 350 m^3/tDM for pig slurry, cattle dung and chicken dung, respectively. Electricity production is based on 1.5 kWh/m^3 (approx. 25% generator efficiency). Annual electricity production potential (at 90% generator availability) is 118,418 kWh/a.

Table 7: Biogas and electricity production potential at Sar Ratha farm

Source	Unit	Average	Minimum	Maximum
Biogas from pig slurry	m^3/d	151	113	190
Biogas from cattle dung	m^3/d	54	54	54
Biogas from chicken dung	m^3/d	35	35	35
Total biogas	**m^3/d**	**240**	**202**	**279**
Total electricity	kWh/d	360	303	418

4.4 Energy demand and supply

4.4.1 Energy demand

At present, energy consumption on the farm site consists of the following:

- Diesel consumption for water pumping. Most of the stables have their own water pump that is used for pumping drinking and cleaning water. There are 11 pumps in total, together consuming some 50 litres of diesel per day.
- Electricity is being supplied from the grid for the households of the workers (18), lighting the stables and running a small (1hp) water pump. Monthly consumption as shown on 3 bills from 2015 averaged 1,370 kWh/month (38 kWh/d) with limited variation (±15%). Current rate is 1,050 KHR/kWh (0.26 US$/kWh).
- Some charcoal is used for heating newborn chicks, and for a few weeks per year for newborn piglets. Average charcoal consumption is approx. 20 bags/month (average 27 kg/d at a price of 0.13 US$/kg).

The farm owner also has a rice mill, some 2 km for the site. It has a capacity of 1 t/h and is driven by a 190hp diesel engine. It is usually operated throughout the year for up to 10 h/d. Exact number of days and hours depends on actual rice demand throughout the year: annual production is some 2,000 t/a, mainly from own stock. Diesel consumption is some 8 l/t of paddy; at an average mill production of 8 t/d this would be 64 l/d. The owner indicated that he would be interested in installing a new mill at the farm, if there would be enough biogas.

The electricity demand of each activity – when driven electrically – would be as shown in Table 8 below. Peak loads of each of the activities could be limited to approx. 40 kVA if motor startup currents can be reduced by e.g. softstarters and/or mechanical clutches. The average daily demand would be 248 kWh/a, and the annual demand would be 72,000 kWh/a. Energy demand of the farm can thus be met with biogas, also when gas availability is low.

Table 8: Potential electricity demand at Sar Ratha farm

Source	Present consumption	Use (d/a)	Use (h/d)	Electricity (kWh/d)	Electricity (kWh/a)	Average power (kW)
Water pumping	50 l/d diesel	365	2	50[a]	18,250	25
Rice milling	64 l/d diesel	250	8	160	40,000	20
Lighting, households	38 kWh/d	365	12	38	13,748	3
Total				248	71,998	

Notes: [a] Judging from the diesel consumption, the pumps in use are very inefficient; an electricity equivalence of 1kWh/l of diesel is assumed

With respect to using biogas for heating of chicks and piglets: replacing the average charcoal consumption would require some 36 m^3/d of biogas. Alternatively, engine heat could be used, if the engine is placed near the stable with the highest heat demand. On the basis of the current charcoal price (0.125 US$/kg) and replacement rate (1.33 m^3 biogas per kg charcoal), using the biogas for this will yield a revenue of some 0.09 US$/$m^3$ which is only a fraction of that for the replacement of diesel or electricity. Using the gas for this purpose should have a low priority.

Figure 27: Diesel fuelled water pump

Figure 28: Sar Ratha rice mill

4.4.2 Supply strategy

The electricity demand at the Sar Ratha farm amounts to approx. 55% of the total electricity production potential. Two production scenarios can be distinguished: i) production of captive power only, and ii) full utilisation of the biogas potential, supplying excess electricity to the grid.

Captive power

In the case of captive power production, the biogas is used for meeting the on-farm electricity demand only. A somewhat smaller digester is required as biogas demand is limited. As the peak load is estimated at 40 kVA, a genset of 50 kVA is proposed.

Full production

In the case of full production, all biogas is converted to electricity, and the electricity not used on-farm is fed into the grid. Also for converting all the biogas to electricity, a genset with 50kVA capacity would be required.

In either case, the operating schedule could look as follows:

- In early morning (7-9am) the system would produce electricity for running water pumps (11 smaller electric pumps of 2-3kW each).
- During daytime (9am-17pm) the engine can drive the rice mill. The (electrical) drive would require a soft-starter and/or a mechanical clutch in order to reduce high motor startup currents.
- During evening hours (18-24pm) the system can produce electricity for on-farm lighting and for supplying households. Additional capacity and biogas can be used for water pumping for the next day and/ or for supplying electricity to the grid (30kW max, 6 h/d).
- Throughout the day, small additional electrical loads (approx. 5-10 kW) are permitted

4.5 GHG emission reductions

Greenhouse gas reductions from this project, in the ***full production*** scenario, are as follows:

- Methane emission reduction is 28.8 t/a (720 tCO_{2eq} /a).
- Diesel fuel reduction (at 90% generator availability) is 30,825 l/a (83 tCO_{2eq} /a).
- Grid electricity substitution (90% generator availability) is 67,368 kWh/a (43 tCO_{2eq} /a)[14].
- Total GHG reduction is thus 846 tCO_{2eq} /a.

In the captive use scenario, they are as follows:

- Methane emission reduction is 26.2 t/a (654 tCO_{2eq} /a).
- Diesel fuel reduction (at 90% generator availability) is 30,825 l/a (83 tCO_{2eq} /a).
- Grid electricity substitution (90% generator availability) is 12,374 kWh/a (8 tCO_{2eq} /a).
- Total GHG reduction is thus 745 tCO_{2eq} /a.

4.6 Biogas plant description

4.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

[14] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as part of the electricity is used on the farm, therby substituting diesel rather than replacing grid electricity

In the ***full production scenario***, the maximum daily amount of waste water (76 m^3/d) and the recommended retention time of 30 days result in a digester volume of 2,300 m^3. In the ***captive power*** scenario, the maximum daily electricity demand that must be met is 248 kWh/d, requiring 165 m^3/d of biogas resulting in a digester of 2,200 m^3 volume[15]. Dimensions of the lagoon will be approx. 50x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 60x25m. Note that these dimensions are provisional and will be set during final design.

Waste water from each stable will flow through a canal into a sedimentation tank (one per stable). It will be pumped from the sedimentation tanks, though underground pipes, into a central collection tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

4.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 40 kW (50 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

In the ***full production*** scenario, grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid, through an MV line of approx. 1km.

Any excess biogas will be burnt off with a flare.

4.7 Financial analyses

4.7.1 Basic parameters

Table 9 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interests are disregarded.

[15] In the captive power scenario, the amount of water remains the same; hence the limited reduction in digester size.

Table 9: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average of salaries that is found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

4.7.2 Investment costs

Table 10 and Table 11 below give an overview of the investment costs of the biogas system at Sar Ratha farm, in both scenarios. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 10: Investment costs Sar Ratha farm biogas system (full production)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	20,000	15	2%
Pumps	6,000	5	5%
Structures	25,000	20	2%
Gas treatment	5,000	10	5%
Generator	19,000	5	10%
Electrical systems	20,000	15	2%
Engineering and installation	5,000	15	0%
Sub-total	**100,000**	**N/A**	**N/A**
Contingencies	10,000	N/A	N/A
Pre-production financial costs	3,654	N/A	N/A
Total investment costs	**113,654**	**N/A**	**N/A**

Table 11: Investment costs Sar Ratha farm biogas system (captive power)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	19,000	15	2%
Pumps	6,000	5	5%
Structures	25,000	20	2%
Gas treatment	5,000	10	5%
Generator	19,000	5	10%
Electrical systems	0	15	2%
Engineering and installation	5,000	15	0%
Sub-total	**79,000**	**N/A**	**N/A**
Contingencies	7,900	N/A	N/A
Pre-production financial costs	2,914	N/A	N/A
Total investment costs	**89,814**	**N/A**	**N/A**

From the tables it can be seen that investment costs in the captive power scenario are 21% below those in the full production scenario. Other options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 6,600 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 9,900 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

In the **full production** scenario, net working capital is estimated at 224 US$; this is built up of accounts receivable (894 US$) minus accounts payable (670 US$). In the captive power scenario, accounts receivable are 0 resulting in a net working capital of -460 US$.

4.7.3 Production costs

Table 12 shows the annual operating and production costs of the biogas system in the ***full production*** scenario, in the first 6 years. Note that in the operating costs, the alternative of cattle and chicken dung takes up the largest part (31%), followed by maintenance of the generator (24%) and staff costs (22%). Financing costs concern interest on loan (see section 4.7.1).

Table 12: Production costs Sar Ratha farm biogas system (full production)

Item / Year	1	2	3	4	5	6
Staff	1,800	1,800	1,800	1,800	1,800	1,800
Dung alternative costs	2,489	2,489	2,489	2,489	2,489	2,489
Maintenance	3,750	3,750	3,750	3,750	3,750	3,750
Operating costs	**8,039**	**8,039**	**8,039**	**8,039**	**8,039**	**8,039**
Depreciation	10,725	10,725	10,725	10,725	10,725	10,725
Financing costs	7,308	5,846	4,385	2,923	1,462	0
Production costs	**26,072**	**24,610**	**23,149**	**21,687**	**20,226**	**18,764**

Annual production costs in the ***captive power*** scenario are shown in Table 13 below. They are approx. 21% lower than in the full production scenario. Largest cost items are now generator maintenance item (34%) and staff costs (33%); dung alternative costs are now just 7%.

Table 13: Production costs Sar Ratha farm biogas system (working capital)

Item / Year	1	2	3	4	5	6
Staff	1,800	1,800	1,800	1,800	1,800	1,800
Dung alternative costs	394	394	394	394	394	394
Maintenance	3,330	3,330	3,330	3,330	3,330	3,330
Operating costs	**5,524**	**5,524**	**5,524**	**5,524**	**5,524**	**5,524**
Depreciation	9,185	9,185	9,185	9,185	9,185	9,185
Financing costs	5,828	4,662	3,497	2,331	1,166	0
Production costs	**20,537**	**19,371**	**18,206**	**17,040**	**15,875**	**14,709**

4.7.4 Revenues

Revenues from the biogas system concern current expenses on diesel for water pumping; avoided diesel use for rice milling; replacement of electricity from the grid; and, in the full production scenario, electricity sales to the local REE. The potential use of gas or engine waste heat for heating to replace charcoal has not been included.

Table 14: Revenue Sar Ratha farm biogas system (full production)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement water pumping	l/a	16,425	0.50	8,213
Diesel replacement rice milling	l/a	14,400	0.50	7,200
Replacement electricity consumption	kWh/a	12,374	0.15	1,856
Grid supply	kWh/a	53,619	0.10	5,362
Total revenue				**22,630**

Table 14 shows the total revenues in the full production scenario. In the ***captive power*** scenario, income from grid supply is omitted, resulting in total annual revenues of 17,269 US$.

4.7.5 Cash flow analysis

Table 15 below shows the project cash-flow for the first 7 years in the ***full production*** scenario (total project period is 15 years). During the first years, annual cash flows are negative; once the loan has been repaid they become positive, with the exception of year 10 when loan reinvestments are required. Cumulative cash flow becomes positive after year 11.

Table 15: Cash flow Sar Ratha farm biogas system (full production)

Item / Year	0	1	2	3	4	5	6
Equity	35,000	0	0	0	0	0	0
Debt financing	79,000	0	0	0	0	0	0
Short term financing	0	670	0	0	0	0	0
Inflow from operations	0	22,630	22,630	22,630	22,630	22,630	22,630
Total inflow	**114,000**	**23,300**	**22,630**	**22,630**	**22,630**	**22,630**	**22,630**
Increase fixed assets	110,000	0	0	0	0	27,500	0
Increase current assets	0	894	0	0	0	0	0
Operating costs	0	8,039	8,039	8,039	8,039	8,039	8,039
Corporate tax	0	0	0	0	189	481	773
Interest payable	3,654	7,308	5,846	4,385	2,923	1,462	0
Loan repayments	0	15,800	15,800	15,800	15,800	15,800	0
Total outflow	**113,654**	**32,040**	**29,685**	**28,224**	**26,951**	**53,282**	**8,813**
Net cash flow	**346**	**-8,740**	**-7,055**	**-5,593**	**-4,320**	**-30,651**	**13,818**
Cumulative	**346**	**-8,394**	**-15,449**	**-21,042**	**-25,363**	**-56,014**	**-42,196**

Table 16 below shows the project cash-flow for the first 7 years of the project in the ***captive power*** scenario. There are negative net cash flows throughout the loan repayment period and in years 10 (21,768 US$). Cumulative cash flow becomes positive in year 13.

Table 16: Cash flow Sar Ratha farm biogas system (captive power)

Item / Year	0	1	2	3	4	5	6
Equity	27,000	0	0	0	0	0	0
Debt financing	63,000	0	0	0	0	0	0
Short term financing	0	460	0	0	0	0	0
Inflow from operations	0	17,269	17,269	17,269	17,269	17,269	17,269
Total inflow	**90,000**	**17,729**	**17,269**	**17,269**	**17,269**	**17,269**	**17,269**
Increase fixed assets	86,900	0	0	0	0	27,500	0
Increase current assets	0	0	0	0	0	0	0
Operating costs	0	5,524	5,524	5,524	5,524	5,524	5,524
Corporate tax	0	0	0	0	46	279	512
Interest payable	2,914	5,828	4,662	3,497	2,331	1,166	2,914
Loan repayments	0	12,600	12,600	12,600	12,600	12,600	0
Total outflow	**89,814**	**23,952**	**22,786**	**21,621**	**20,501**	**47,068**	**6,036**
Net cash flow	**186**	**-6,223**	**-5,518**	**-4,352**	**-3,232**	**-29,800**	**11,232**
Cumulative	**186**	**-6,037**	**-11,554**	**-15,906**	**-19,139**	**-48,939**	**-37,706**

Table 17 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity production (LCOE) of 0.279 US$/kWh, which is high in comparison to grid prices and diesel-based energy (>0.25 US$/kWh).

Table 17 shows financial indicators calculated from the cash flows for both scenarios. For the ***full production*** scenario, the Levelised Cost of Electricity (LCOE) of 0.279 US$/kWh, which is high in comparison to grid prices but well below the current cost of running the diesel pumps (estimated 0.50 US$/kWh). Simple Payback Period is approx. 7.8 years.

In the ***captive power*** scenario, LCOE is 0.402 US$/kWh which considerably higher than in the full production scenario, but still somewhat below the current costs of diesel-powered water pumps. Simple Payback Period is 7.6 years.

Table 17: Indicators Sar Ratha farm biogas system

Item	Unit	Full production	Captive use
LCOE	US$/kWh	0.279	0.402
IRR	%	5%	4%
NPV	US$	-45,005	-37,977
Simple Payback Period	years	7.8	7.6

4.7.6 Sensitivity analysis

The cashflow analyses show somewhat better economic results for the full production scenario; the sensitivity analysis is therefore limited to this scenario only. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM; in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.

- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 29 below.

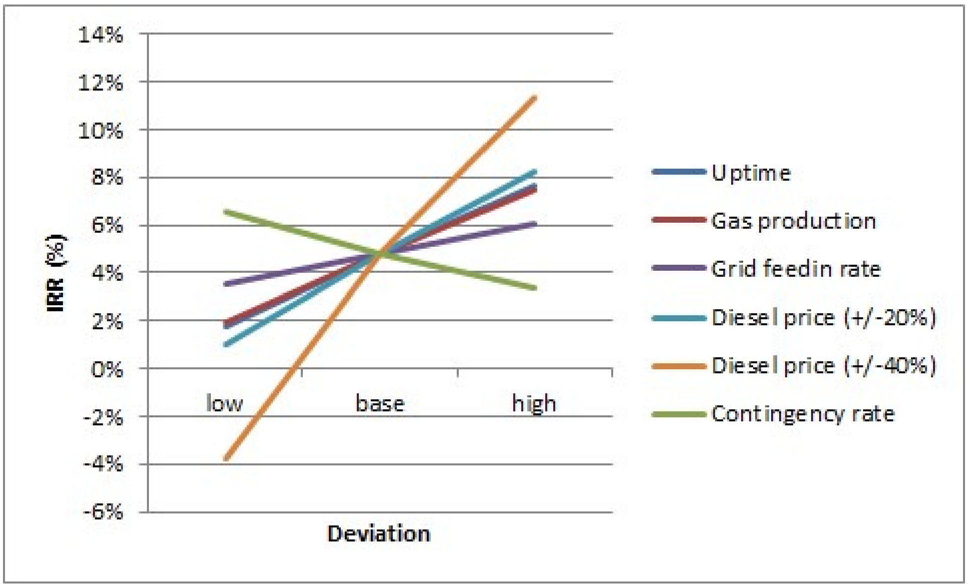

Figure 29: Sensitivity analysis Sar Ratha biogas project

The results show that sensitivity to grid feed-in rate (±20%) and investment costs (contingency rate 10±10%) is limited, resulting in IRR changes of approx. ±1.5% points. Sensitivity to generator uptime (90±10%) and gas production (±20%) is slightly higher, resulting in IRR changes of approx. ±3% points. Sensitivity to diesel price is high; ±20% deviations result in IRR changes of approx. ±3.5% points, while ±40% deviations result in IRR changes of approx. ±7-8% points.

Combinations of deviations of different variables may result in larger IRR fluctuations. There are many possible combinations; some examples:

- Increased gas production (+20%), higher diesel price (+20%) and higher investment costs (20% contingency rate) results in an IRR of 9%.
- Reduced generator uptime (80%) plus lower feed-in rate (-20%) result in an IRR of 1%.
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%) lower diesel price (-20%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of -8% (18 years simple payback period)
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%) higher diesel price (+20%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 17% (4 years simple payback period).

Note that selecting another generator or reducing water consumption (see section 4.7.2) have very little effect on project viability. Choosing a modified diesel engine can slightly increase IRR; the lower investment costs barely weigh up to the shorter lifetime of such a genset. Reduced water consumption results in a smaller digester unit but the over-all investment cost reduction is limited.

4.8 Conclusions

The average biogas production potential at Sar Ratha farm is approx. 240 m^3/d, with fluctuations of ±15%. Both a full production scenario and a captive power scenario have been assessed:

- The ***full production*** scenario features a covered lagoon digester with a volume of 2,300 m^3 and a 40 kW (50 kVA) gas generator. Electricity production potential is approx. 360 kWh/d on average (118,418 kWh/a) which can be partly used on the farm and partly fed into the local REE distribution grid.
- In the ***captive power*** scenario, a daily electricity demand of 248 kWh/d should be met, requiring 165 m^3/d of biogas. Required digester volume is 2,200 m^3 and generator capacity of 40 kW (50 kVA).

Total investment costs of the ***full production*** system is 113,654 US$; for the ***captive power*** system it is 89,814 US$. Production costs are also lower (approx. 21%) but so are revenues. Over all, economics are similar, albeit slightly better for the full production scenario: respectively IRR of 5% and 4%, and Simple Payback period of 7.6 and 7.8 years. Sensitivity is particularly sensitive to diesel price fluctuations.

5 FEASIBILITY STUDY: PICH ROBIN

Table 18: Pich Robin farm location and contact

Farm	Pich Robin
Village	Tbeng Kang Kert
Commune	Tbeng
District	Banteay Srey
Province	Siem Reap
GPS	13.5501N, 104.0714E
Owner	Mr. Pich Robin 012 217 556

5.1 Introduction

The farm of Mr. Pich Robin is located in Siem Reap province, Banteay Srey district, some 15 km west from the district capital Banteay Srey. The farm is a fattening farm, one of many farms working under contract for C.P. Cambodia, a large feed and livestock company. The farm has 8 stables with a holding capacity of 600 heads, i.e. a total capacity of 4800 heads. Total land owned by the owner is approx. 20 ha.

Figure 30: Map of Pich Robin farm

5.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months from approx. 7kg to 100-120kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

Note that C.P. practices an “all in, all out” system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease.

Feeding is done with CP feed, following C.P. procedures. Feeding is increased gradually, from 0-1.5 kg/head/day in the first 70 days; then from 1.5 to 2.5 kg/head/day until 138 days. After that, feeding is stable at 2.5 kg/head/day.

The layout of the stables is as prescribed by C.P. Each stable has 26 pens, each holding 23 pigs. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4x1.5x0.15m = 0.9m^3) are always filled with water; fresh water flows in on one side of the stable, taking out the urine and dung that is dropped in it. Every two days, all the solid dung in the dry part of the pens is pushed into the water, and all the water is completely refreshed (approx. 24m^3 per stable). Every week, all the pens are hosed down.

5.3 Biogas feedstock

5.3.1 Manure and urine production

Average daily dung production is some 3.8 tonnes. However, because of the “all in, all out” system and the animal feeding pattern, there is a large variation in dung availability. At the start of each cycle, when the farm houses small piglets, dung production will be negligible. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). After the stables have been cleared out, there is a period of 2-4 weeks where there is no dung production at all. Fresh dung production will thus vary between 0 and approx. 7.5 t/d. Total dry matter production (including solids from urine) will be approx. 1.4 t/d, varying between 0 and 2.9 t/d.

The dung (and cleaning water) flow from the back of each stable into two ponds inbetween the stables (10x20x4m and 15x20x4m). From there, the water flows to a third pond on the north side of the premises, from where it flows by underground pipe to a 3 ha rice field owned by the farmer, a few hundred metres away.

Urine production will also vary throughout the cycle, but is on average 12m^3/d.

Figure 31: Slurry pond at Pich Robin farm

Figure 32: Interior of one of the stables

5.3.2 Water consumption

Water supply to the Pich Robin farm comes from a well in the nearby mountains, and is piped down to the farm over a distance of approx. 2km. There are no pumps, no energy consumption and no costs, so there is no incentive to economize on water usage.

Apart from drinking water, water consumption at the farm totals approx. 129m^3/d (based on spot water flow measurements). It consists of the following components:

- Continuous refreshment of bathing water. In the front of each stable, fresh water flows into the baths, and in the back the water flows out. The water flow per stable is approx. 5.5m^3 per day, or 44m^3/d for the whole farm.
- Every two days, all the bathing water is completely refreshed. This constitutes approx. 21m^3 per stable, on average 76m^3/d for the whole farm.
- Every week, all the pens are hosed down, using some 8m^3 of water per stable. This is an average water consumption of 9m^3 per day for the farm.

Water evaporation is estimated at 0.5 m^3/d/stable or 4 m^3/d.

5.3.3 Total waste production

Total waste production is shown in Table 6 below. Waste production (29 l/head/day) is among the lowest found in industry.

Table 19: Total waste production at Pich Robin farm

Source	Unit	average	minimum	maximum
Water	t/d	129	129	129
Dung (fresh)	t/d	3.8	0.0	7.5
Urine	t/d	12	0	24
Evaporation	t/d	4.0	4.0	4.0
Total waste water	t/d	141	125	156
DM content	%	1.0%	0.0%	1.8%

Despite the abundant availability of water, waste production (29 l/head/day) is significantly below the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d).

5.3.4 Biogas and electricity production potential

Table 20 below gives an overview of the biogas and electricity production potential at Pich Robin farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency). Annual electricity production potential would be 241,250 kWh/a.

Table 20: Biogas and electricity production potential at Pich Robin farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	432	0	864
Total electricity	kWh/d	734	0	1,468
Total electricity (at 90% genset availability)	kWh/a	241,250		

5.4 Energy demand and supply

5.4.1 Energy demand

Energy demand is very low at the Pich Robin farm. There are no water pumps, and there is just some electricity consumption for lighting of stables, TV and DVD but this is covered by a small PV set. When the stables are emptied (twice per year), some additional lights are used, for which a small gasoline generator is used.

In the absence of on-farm energy demand, the biogas will be converted to electricity and supplied to the grid.

5.4.2 Supply strategy

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (864 m^3/d) in a maximum number of hours per day (e.g. 16 h/d). At 90% loading rate this results in a 100kW (125kVA) genset. In periods of low biogas availability, running hours will decrease, so that optimum generator loading rate can be maintained.

The farm of Pich Robin is located in the EDC concession area. EDC has indicated to be interested in buying electricity only during dry season (January-June), when hydropower availability is lowest. As such, the plant could supply to the grid for up to 6 months per year.

5.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 81.7 t/a (2,042 tCO_{2eq} /a).
- Grid electricity substitution in 120,625 kWh/a (79 tCO_{2eq} /a)[16].
- Total GHG reduction is thus 2,122 tCO_{2eq} /a.

5.6 Biogas system description

5.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (156 m^3/d) and the recommended retention time of 30 days, digester volume is set at 4,700 m^3. Dimensions of the lagoon will be approx. 60x22x6 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 70x32m. Note that these dimensions are provisional and will be set during final design.

[16] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as grid demand (by EDC) is only a fraction of the potential

Waste water will flow from all the stables through canals into a central sedimentation tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to the fields by underground pipe, as is currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

5.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 100 kW (125 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid.

Any excess biogas will be burnt off with a flare.

5.7 Financial analyses

5.7.1 Basic parameters

Table 21 shows the basic parameters used in the financial calculations.

Table 21: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on indications from EDC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interests are disregarded.

5.7.2 Investment costs

Table 22 below gives an overview of the investment costs of the biogas system at Pich Robin farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 22: Investment costs Pich Robin farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	29,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	6,000	10	5%
Generator	32,000	5	10%
Electrical systems	11,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**89,000**	**N/A**	**N/A**
Contingencies	8,900	N/A	N/A
Pre-production financial costs	3,284	N/A	N/A
Total investment costs	**101,184**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 4,400 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 17,600 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at some 1,651 US$; this is built up of accounts receivable (1,997 US$) minus accounts payable (346 US$).

5.7.3 Production costs

Table 23 shows the annual operating and production costs of the biogas system. Note that in the operating costs, maintenance of the generator takes up the largest part (48%), followed by staff costs (22%) and digester maintenance (14%) The remainder is maintenance for other equipment.

Table 23: Production costs Pich Robin farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	3,250	3,250	3,250	3,250	3,250	3,250
Operating costs	**4,150**	**4,150**	**4,150**	**4,150**	**4,150**	**4,150**
Depreciation	11,495	11,495	11,495	11,495	11,495	11,495
Financing costs	6,568	5,254	3,941	2,627	1,314	0
Production costs	**22,213**	**20,899**	**19,586**	**18,272**	**16,959**	**15,645**

5.7.4 Revenues

Revenues from the biogas system concern sales to the EDC grid only. There is virtually no energy demand on-site (electricity or diesel).

Table 24: Revenue Pich Robin farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	120,625	0.100	12,063
Total revenue				**12,063**

EDC has indicated to be willing to consider a price level below 0.10 US$/kWh, but that they will only purchase electricity during the dry season (January-May/June). The quantity of electricity sold is therefor set at 50% of the potential (see section 5.3.4).

5.7.5 Cash flow analysis

Table 25 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Net cash flows remain positive after year6, with the exception of year 10 when a reinvestment is required. Cumulative cash flows remain below 0 throughout the project period.

Table 25: Cash flow Pich Robin farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	31,000	0	0	0	0	0	0
Debt financing	71,000	0	0	0	0	0	0
Short term financing	0	346	0	0	0	0	0
Inflow from operations	0	12,063	12,063	12,063	12,063	12,063	12,063
Total inflow	**102,000**	**12,408**	**12,063**	**12,063**	**12,063**	**12,063**	**12,063**
Increase fixed assets	97,900	0	0	0	0	36,300	0
Increase current assets	0	2,010	0	0	0	0	0
Operating costs	0	4,150	4,150	4,150	4,150	4,150	4,150
Corporate tax	0	0	0	0	0	0	0
Interest payable	3,284	6,568	5,254	3,941	2,627	1,314	0
Loan repayments	0	14,200	14,200	14,200	14,200	14,200	0
Total outflow	**101,184**	**26,928**	**23,604**	**22,291**	**20,977**	**55,964**	**4,150**
Net cash flow	**816**	**-14,520**	**-11,541**	**-10,228**	**-8,914**	**-43,901**	**7,913**
Cumulative	**816**	**-13,703**	**-25,245**	**-35,473**	**-44,387**	**-88,288**	**-80,376**

Corporate tax is 0 as total production costs (including depreciation) are higher than annual revenues.

Table 26 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.231 US$/kWh, in contrast to the tariff of 0.100 US$/kWh that can be expected of EDC. Only at a rate of 0.227 US$/kWh, the project would reach an IRR of 14%.

Table 26: Indicators Pich Robin farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.231
IRR	%	-7%
NPV	US$	-80,406
Simple Payback Period	years	12.8 years

5.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

Note that in the absence of diesel consumption on the farm, there is no sensitivity to diesel price.

The results of the analysis are show in Figure 33 below.

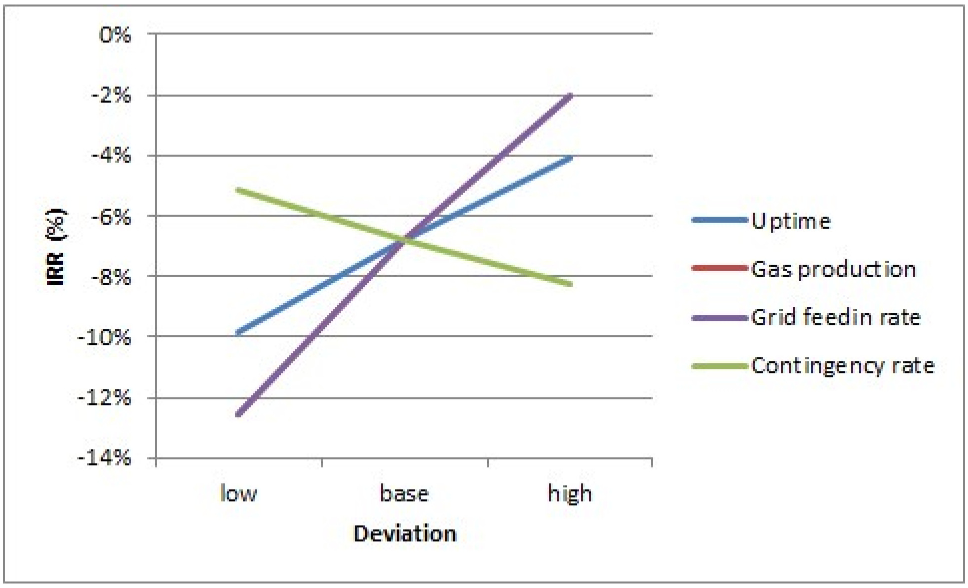

Figure 33: Sensitivity analysis Pich Robin biogas project

The results show that variations in grid feed-in tariff and gas production (line is covered by grid feed-in tariff line) have identical consequences: both result in IRR changes of approx. 5% points. Generator availability changes (80-100%) result in IRR changes of ±3% points; investment costs deviations have the smallest consequences (IRR changes of 1.5% points).

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%) and lower investment costs (0% contingency rate) results in an IRR of 0%.
- Reduced generator uptime (80%) and lower feed-in rate (-20%) result in an IRR of -16%.
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%), lower feed-in tariff (-20%), higher contingency rate (20%), results in a payback period of 40 years.

- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 7% (6.1 years payback period).

Increases in electricity demand have the largest effect on project economics. If EDC demand would extend into the rainy season as well, IRR would increase to 9%. Alternatively, if on-farm demand would be created – e.g. by introducing closed stables (60,000 kWh/a), IRR would be 3%.

Note that the result of selecting a low-cost solution for the generator will have limited effect on the project IRR (changes to -5%), as will a 25% reduction in water consumption (changes to -6%).

5.8 Conclusions

The average biogas production potential at Pich Robin farm is approx. 432 m^3/d, with fluctuations of ±100% due to the all-in, all-out system practiced. Electricity production potential is approx. 734 kWh/d on average (241,250 kWh/a). The project features a covered lagoon digester with a volume of 4,700 m^3 and a 100 kW (125 kVA) gas generator. Total investment is 101,184 US$.

Because of the seasonal demand of electricity by EDC and the absence of energy demand on-site, capacity utilisation is only about 50% resulting in a Levelised Cost of Electricity of 0.231 US$/kWh as compared to the 0.100 US$/kWh indicated by EDC. The Simple Payback period is 12.8 years. Increasing EDC demand, and/or development of on-farm electricity demand, could be seen as a prerequisite for project implementation.

6 FEASIBILITY STUDY: TE SOPHEAK

Table 27: Te Sopheak farm location and contacts

Farm	Te Sopheak
Village	Rovieng
Commune	Romchek
District	Banteay Srey
Province	Siem Reap
GPS	13.5311N, 103.9855E
Owner	Mr. Te Sopheak 012 771 718

6.1 Introduction

The farm of Mr. Te Sopheak is located in Siem Reap province, Banteay Srey district, some 10km south of the district capital Banteay Srey. The farm is a fattening farm, one of many farms working under contract for C.P. Cambodia, a large feed and livestock company. The farm has 2 stables with a holding capacity of 600 heads each, i.e. a total capacity of 1200 heads. The farm is located next to the farm of Eang Souleng (same size, see chapter 8) and two other – larger – pig farms (2,400 and 7,200 heads, respectively).

Figure 34: Map of Te Sopheak farm

6.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months from approx. 7 kg to 100-120 kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

Note that C.P. practices an "all in, all out" system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease.

Feeding is done with CP feed, following C.P. procedures. Feeding is increased gradually, from 0-1.5 kg/head/day in the first 70 days; then from 1.5 to 2.5 kg/head/day until 138 days. After that, feeding is stable at 2.5 kg/head/day.

The layout of the stables is as prescribed by C.P. Each stable has 26 pens, each holding 23 pigs. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4x1.5x0.15m = 0.9 m^3) are always filled with water, which is changed every day. Cleaning of the pens is also done every day.

6.3 Biogas feedstock

6.3.1 Manure and urine production

Average daily dung production is estimated at 0.94 tonnes per day. However, because of the "all in, all out" system and the animal feeding pattern, there is a large variation in dung availability. At the start of each cycle, when the farm houses small piglets, dung production will be negligible. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). After the stables have been cleared out, there is a period of 2-4 weeks where there is no dung production at all. Fresh dung production will thus vary between 0 and approx. 1.9 t/d. Total dry matter production (including solids from urine) will be approx. 0.36 t/d, varying between 0 and 0.72 t/d.

Urine production will also vary throughout the cycle, but is on average 3m^3/d.

The dung, urine and cleaning water from each stable flow into two ponds located behind each stable (15x15m and 20x30m). There is no slurry removal; water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

6.3.2 Water consumption

Water for the Te Sopheak farm is pumped from a borehole on the farm site. Apart from drinking water, water consumption at the farm totals approx. 56 m^3/d (based on spot water flow measurements). It consists of the following components:

- Cleaning of the pens. This is done every day with a hose, which takes approx. 2 hours. Total water consumption for the two stables is approx. 14 m^3/d.
- Refreshing the bath water. This is done every day after cleaning. The level of the bathing water increases with the age of the pigs, starting from 1/3 filled to fully filled after few months. Daily water consumption is up to 42 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 1 m^3/d.


Figure 35: Water pump at Te Sopheak farm


Figure 36: Waste water pond

6.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 28 below.

Table 28: Total waste production at Te Sopheak farm

Source	Unit	average	minimum	maximum
Water	t/d	57	57	57
Dung (fresh)	t/d	0.9	0.0	1.9
Urine	t/d	3.0	0	6.0
Evaporation	t/d	1.0	1.0	1.0
Total waste water	t/d	59	56	63
DM content	%	0.6%	0.0%	1.1%

Waste production, 50 l/head/d, is significantly above the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d). A reduction of the water consumption (e.g. by closing off water when not in use, or using pressurized water for hosing) would somewhat reduce the required biogas system volume, and the energy consumption of water pumps.

6.3.4 Biogas and electricity production potential

Table 29 below gives an overview of the biogas and electricity production potential at Te Sopheak farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.5 kWh/m^3 (approx. 25% generator efficiency, due to small size). Annual electricity production potential would be 59,130 kWh/a.

Table 29: Biogas and electricity production potential at Te Sopheak farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	108	0	216
Total electricity	kWh/d	162	0	324
Total electricity (at 90% genset availability)	kWh/a	53,217		

6.4 Energy demand and supply

6.4.1 Energy demand

Energy demand is limited at Te Sopheak farm. Main energy consumer is the water pump, which runs for approx. 5 hours per day, consuming 5 litres of diesel. There is a small 3 kVA diesel generator, which normally runes for 3 hours per day for the workers; during the first 3 weeks of the fattening it runs for 5 h/d to provide lighting in stables so that the piglets can eat. Full load was measured at approx. 350W; daily consumption is thus some 1-1.7 kWh/d; average fuel consumption is 1 l/d.

On the basis of fuel consumption, water pumping is expected to consume some 12 kWh/day when done with an electric pump. Adding the current electricity consumption, total demand would be about 14 kWh/d or 6,183 kWh/a. Electrical load would be approx. 3 kW during pumping.

6.4.2 Supply strategy

On-site electricity demand is less than 10% of the average electricity production potential, and less than 5% of the maximum production potential. Most of the energy would thus have to be supplied to a grid.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (216 m^3/d) in a maximum number of hours per day (e.g. 16 h/d). At 90% loading rate this results in a 24kW (30kVA) genset.

In periods of low biogas availability, the generator should run only for powering the water pump. This will require some 10-20 m^3/d of gas; any biogas in storage can then cover a longer period of supplying own electricity demand. It is estimated that there would be sufficient gas for water pumping during 11 months per year, and for on-farm electricity consumption during 8 months per year.

6.5 System alternative

One possible system alternative would be to combine the waste resources of multiple farms, in order to achieve a larger scale – if sanitary regulations of C.P. would allow this (see section 2.3). In this case, collaboration with the neighbouring farm of Eang Souleng (see chapter 8) could be considered. There are other farms in the vicinity as well, but these do not participate in the project. The collaboration could result in a smaller fluctuation in dung availability, if the ”all-in, all-out” cycles of the two farms are out of phase. Also, the biogas could sustain a larger, more efficient, generator set. The result of this alternative will be presented in the sensitivity analysis (section 6.8.6).

6.6 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 20.4 t/a (511 tCO_{2eq} /a).
- Diesel substitution is 1,701 l/a (5 tCO_{2eq} /a).

- Grid electricity substitution is 24,276 kWh/a (16 tCO_{2eq} /a)[17].
- Total GHG reduction is thus 533 tCO_{2eq} /a.

6.7 Biogas plant description

6.7.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (63 m^3/d) and the recommended retention time of 30 days, digester volume is set at 1,900 m^3. Dimensions of the lagoon will be approx. 45x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 55x25m. Note that these dimensions are provisional and will be set during final design.

Waste water will flow from the stables through canals into a central sedimentation tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

6.7.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 24 kW (30 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid.

Any excess biogas will be burnt off with a flare.

[17] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as 1) part of the electricity is used on the farm, therby substituting diesel rather than replacing grid electricity; 2) generator availability is 90%; and 3) grid demand (by EDC) is only 50% of the time

6.8 Financial analyses

6.8.1 Basic parameters

Table 30 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interests are disregarded.

Table 30: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on indications from EDC

6.8.2 Investment costs

Table 31 below gives an overview of the investment costs of the biogas system at Te Sopheak farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 31: Investment costs Te Sopheak farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	18,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	5,000	10	5%
Generator	14,000	5	10%
Electrical systems	8,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**56,000**	**N/A**	**N/A**
Contingencies	5,600	N/A	N/A
Pre-production financial costs	2,081	N/A	N/A
Total investment costs	**63,681**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with 2,200 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with 7,700 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at 180 US$; this is built up of accounts receivable (405 US$) minus accounts payable (225 US$).

6.8.3 Production costs

Table 32 shows the annual operating and production costs of the biogas system in the first 6 years. Note that in the operating costs, staff costs take up the largest part (33%), followed by maintenance of the generator (32%) and digester maintenance (13%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 6.8.1), these will remain 0 from year 6 onwards.

Table 32: Production costs Te Sopheak farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	1,795	1,795	1,795	1,795	1,795	1,795
Operating costs	**2,695**	**2,695**	**2,695**	**2,695**	**2,695**	**2,695**
Depreciation	6,398	6,398	6,398	6,398	6,398	6,398
Financing costs	4,163	3,330	2,498	1,665	833	0
Production costs	**13,256**	**12,423**	**11,591**	**10,758**	**9,926**	**9,093**

6.8.4 Revenues

Revenues from the biogas system concern diesel consumption reductions and sales to the EDC grid.

Table 33: Revenue Te Sopheak farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	24,276	0.10	2,562
Diesel reduction	Litres	1,701	0.50	851
Total revenue	**US$**			**3,278**

EDC has indicated to be willing to consider a price level below 0.10 US$/kWh, but that they will only purchase electricity during the dry season (January-May/June). The quantity of electricity sold is therefore set at 50% of the potential, at a price of 0.10 US$/kWh (see section 6.3.4).

6.8.5 Cash flow analysis

Table 34 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Throughout the load repayment period, cash flows are negative; only from year 6 onwards there are small positive cash flows, with the exception of year 10 (US$ -21,417). Cumulative cash flow does not become positive during the 15 year project period.

Corporate tax is 0 as total production costs (including depreciation) are higher than annual revenues.

Table 35 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.583 US$/kWh, in contrast to the tariff of 0.100 US$/kWh that is expected from EDC.

Table 34: Cash flow Te Sopheak farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	19,000	0	0	0	0	0	0
Debt financing	45,000	0	0	0	0	0	0
Short term financing	0	225	0	0	0	0	0
Inflow from operations	0	3,278	3,278	3,278	3,278	3,278	3,278
Total inflow	**64,000**	**3,503**	**3,278**	**3,278**	**3,278**	**3,278**	**3,278**
Increase fixed assets	61,600	0	0	0	0	16,500	0
Increase current assets	0	405	0	0	0	0	0
Operating costs	0	2,695	2,695	2,695	2,695	2,695	2,695
Corporate tax	0	0	0	0	0	0	0
Interest payable	2,081	4,163	3,330	2,498	1,665	833	0
Loan repayments	0	9,000	9,000	9,000	9,000	9,000	0
Total outflow	**63,681**	**16,262**	**15,025**	**14,193**	**13,360**	**29,028**	**2,695**
Net cash flow	**319**	**-12,759**	**-11,747**	**-10,914**	**-10,082**	**-25,749**	**583**
Cumulative	**319**	**-12,441**	**-24,188**	**-35,102**	**-45,184**	**-70,933**	**-70,350**

Table 35: Indicators Te Sopheak farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.583
IRR	%	N/A
NPV	US$	-72,151
Simple Payback period	years	109 years

6.8.6 Sensitivity analysis

The indicators in Table 35 show a project with poor economic outlook. There are many factors contributing to this, but the most important are the low energy demand on the farm, and the restricted demand of EDC. A change in the demand situation should therefore be seen as a first prerequisite for project potential:

- Grid supply throughout the year would result in a project IRR of -13% and a payback period of 26 years.
- Increasing on-farm electricity demand with 15,000 kWh/a (e.g. by applying closed stable systems) would result in a project IRR of -16% and a payback period of 33 years.
- A combination of the two would result in an IRR of -11% and a payback period of 20 years.

The sensitivity to other variables will be tested under the assumption that electricity can be supplied to the grid throughout the year. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM; in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.

- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 37 below.

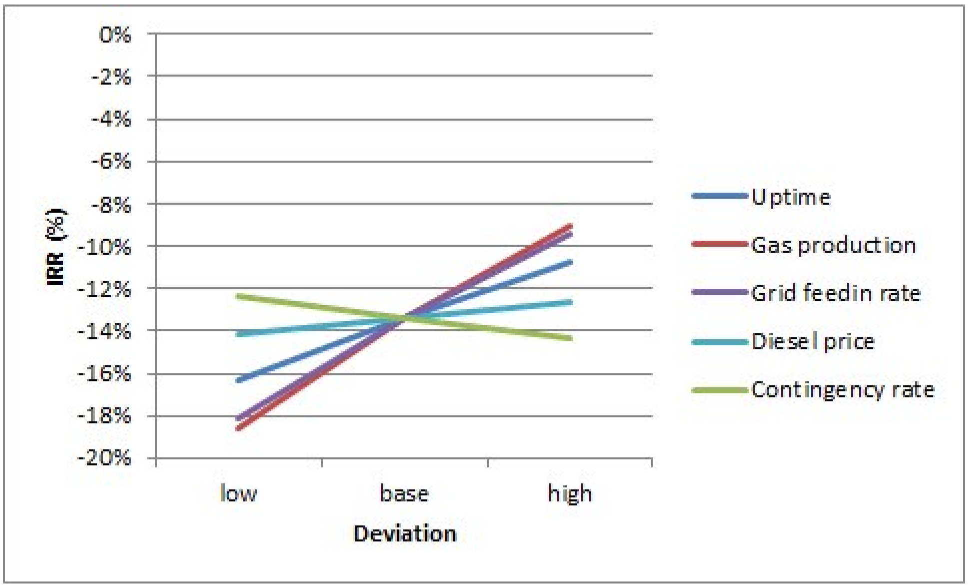

Figure 37: Sensitivity analysis Te Sopheak biogas project

The results show that sensitivity to diesel price (±20% variations) and investment costs (contingency rate 10±10%) are limited; deviations to the standard values result in IRR changes of approx. 1% point. Sensitivity to generator uptime (90±10%) is slightly higher, resulting in IRR changes of approx. 3% points. Sensitivity to grid feed-in tariff (±20%) and gas production (±20%) is high; deviations result in IRR changes of 4-5% points.

Selecting another generator or reducing water consumption (see section 6.8.2) has little effect on project viability. Choosing a modified diesel engine can reduce payback period from 26 to 23 years but has no significant effect on IRR. A water reduction of 25% results in a smaller digester unit but the over-all investment cost reduction is limited. Payback period changes to 24 years but no significant effect on IRR.

The system alternative mentioned in section 6.5 has a positive effect on project economics but does not lead to a viable business case. It would result in a 3,600 m^3 digester with a 50 kVA gas generator. Investment costs increase to approx. 87,000 US$, and IRR to -10% (Simple Payback Period of 20 years). As indicated, this would be under the assumption that this mode of collaboration would be possible within the context of C.P. contract farming.

6.9 Conclusions

The average biogas production potential at Te Sopheak farm is approx. 108 m^3/d, with fluctuations of ±100% due to the all-in, all-out system practiced. Electricity production potential is approx. 162 kWh/d on average (53,217 kWh/a). The project features a covered lagoon digester with a volume of 1900 m^3 and a 24 kW (30 kVA) gas generator. Total investment is 63,681 US$.

The scale of the system is limited, and with the seasonal demand of electricity by EDC the Levelised Cost of Electricity is 0.524 US$/kWh as compared to a possible feed-in rate of 0.10 US$/kWh and an electricity tariff of 0.15 US$/kWh. Continuous grid supply (also during rainy season) and/or increased on-site electricity demand should be considered first prerequisites for developing project potential.

7 FEASIBILITY STUDY: NGET SOVANAROTH

Table 36: Nget Sovanaroth farm location and contact

Farm	Nget Sovanaroth
Village	Sneurdekcho
Commune	Balamng
District	Prasat Bakong
Province	Siem Reap
GPS	13.4425N, 104.0601E
Owner	Mr. Nget Sovanarath 097 994 6886, 097 550 0312

7.1 Introduction

The farm of Mr. Nget Sovanaroth is located in Siem Reap province, Prasat Bakong district, some 10km northeast of the district capital Prasat Bakong. The farm is a fattening farm, one of many farms working under contract for C.P. Cambodia, a large feed and livestock company. The farm has 3 stables with a holding capacity of 610 heads each, i.e. a total capacity of 1,830 heads. Around the farm, the owner has 85 ha of land under rice and mango trees.

Figure 38: Map of Nget Sovanaroth farm

7.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months from approx. 6kg to 100-110kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a few weeks, new piglets are brought for the next cycle.

Note that C.P. practices an "all in, all out" system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease.

Feeding is done with CP feed, following C.P. procedures. Feeding is increased gradually, to 1.5 kg/head/day in the first 70 days; then from 1.5 to 2.5 kg/head/day until 138 days. After that, feeding is stable at 2.5 kg/head/day.

The layout of the stables is as prescribed by C.P. Each stable has 26 pens, each holding 24 pigs. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4x1.5x0.15m = 0.9 m^3) are always filled with water, which is changed every day after the solid manure in the pen has been pushed in the bath. Cleaning of the pens with water is done twice per week.

7.3 Biogas feedstock

7.3.1 Manure and urine production

Average daily dung production is estimated at 1.4 tonnes per day. However, because of the "all in, all out" system and the animal feeding pattern, there is a large variation in dung availability. At the start of each cycle, when the farm houses small piglets, dung production will be negligible. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). After the stables have been cleared out, there is a period of 2-4 weeks where there is no dung production at all. Fresh dung production will thus vary between 0 and approx. 2.9 t/d. Total dry matter production (including solids from urine) will be approx. 0.55 t/d, varying between 0 and 1.1 t/d.

Urine production will also vary throughout the cycle, but is on average 4.6 m^3/d.

The dung, urine and cleaning water from all stables flow into a pond located behind the stables (30x30x4m). A second pond has been dug but is not yet in use. From the pond, the slurry is pumped into a system of canals surrounding the 85ha of land; from there it is pumped onto the rice fields and mango tree land.

7.3.2 Water consumption

Water for the Nget Sovanaroth farm is pumped from a borehole on the farm site into and into a number of 10,000 l storage tanks in front of each stable. Apart from drinking water, the total water consumption at the farm totals approx. 73 m^3/d (based on spot water flow measurements) or 40 l/head/d. It consists of the following components:

- Cleaning of the pens. This is done twice per week with a hose, which takes approx. 4 hours per stable. Total water consumption for cleaning one stable is approx. 12 m^3; average water consumption for the farm is 10m^3/d.
- Refreshing the bath water. This is done every day, which requires some 23m^3 per stable or 63m^3/d for the whole farm.

Water evaporation is estimated at 0.5 m^3/d/stable or 1.5 m^3/d in total.

7.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 6 below.

Table 37: Total waste production at Nget Sovanaroth farm

Source	Unit	average	minimum	maximum
Water	t/d	73	73	73
Dung (fresh)	t/d	1.4	0.0	2.9
Urine	t/d	5	0	9
Evaporation	t/d	1.5	1.5	1.5
Total waste water	t/d	78	72	84
DM content	%	0.7%	0.0%	1.3%

This waste production (43 l/head/d) is equal to the average found in the sector (43 l/head/d) but significantly above the average found in e.g. Vietnam (approx. 30 l/head/d).A reduction of the water consumption (e.g. by closing off water when not in use, or using pressurized water for hosing) would somewhat reduce the biogas system volume, and the energy consumption of water pumps.

7.3.4 Biogas and electricity production potential

Table 20 below gives an overview of the biogas and electricity production potential at Nget Sovanaroth farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency). Annual electricity production potential would be 102,196 kWh/a.

Table 38: Biogas and electricity production potential at Nget Sovanaroth farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	165	0	329
Total electricity	kWh/d	280	0	560
Total electricity (at 90% genset availability)	kWh/a	91,977		

7.4 Energy demand and supply

7.4.1 Energy demand

Energy demand at the Nget Sovanaroth pig farm is covered with a diesel generator, consisting of a 26kW engine and a (estimated) 30kVA alternator. The set runs for 4-5 hours, powering 7 electric water pumps of 0.75 kW each. Fuel consumption is approx. 10 litres per day. The generator used to run also during evenings, for production of electricity for lighting and for the worker's houses, but the additional fuel consumption (5 l/d) was considered too expensive.

In addition, there are 5 diesel driven irrigation pumps that pump water from the canals into the fields. Fuel consumption is approx. 100 litres per month.

On the basis of these data, the potential electricity demand on the farm is estimated as follows:

- Water pumping: 25 kWh/d.
- Lighting and worker's houses: 8 kWh/d.

- Irrigation: 8 kWh/d.
- Total demand: 41 kWh/d or 14,900 kWh/a.

Typical power demand on the pig farm will be approx. 5kW during water pumping, and 1-2kW during evening hours. Power demand for the irrigation pumps is unknown but is expected to be below 5kW per pump.

Figure 39: Stables at Ngeth Sovannaroth farm

Figure 40: Irrigation pump

7.4.2 Supply strategy

On-site electricity demand is approx. 15% of the average production potential, and approx. 8% of the production during peak biogas availability. Most of the energy would thus have to be supplied to a grid.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (560 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 40kW (50kVA) genset.

In periods of low biogas availability, the generator should run only for powering the water pumps. This will require some 20-30 m^3/d of gas; any biogas in storage can then cover a longer period of supplying own electricity demand. It is estimated that there would be sufficient gas for water pumping during 11 months per year, and for on-farm electricity consumption and irrigation during 8 months per year.

7.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 31.1 t/a (779 tCO_{2eq} /a).
- Diesel substitution is 4,763 l/a (13 tCO_{2eq} /a).
- Grid electricity substitution in 78,563 kWh/a (52 tCO_{2eq} /a)[18].
- Total GHG reduction is thus 843 tCO_{2eq} /a.

[18] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential, as part of the electricity is used on the farm, therby substituting diesel rather than replacing grid electricity. Also, generator availability is set at 90%.

7.6 Biogas plant description

7.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (84 m^3/d) and the recommended retention time of 30 days, digester volume is set at 2,500 m^3. Dimensions of the lagoon will be approx. 55x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 65x25m. Note that these dimensions are provisional and will be set during final design.

Waste water will flow from the stables through canals into a central sedimentation tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to the fields through the system of canals surrounding the farm land and from there spread to the fields, as is currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

7.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 40 kW (50 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer and connected to the MV grid through an MV line (approx. 1km).

Any excess biogas will be burnt off with a flare.

7.7 Financial analyses

7.7.1 Basic parameters

Table 39 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interests are disregarded.

Table 39: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on indications from EDC

7.7.2 Investment costs

Table 40 below gives an overview of the investment costs of the biogas system at Nget Sovanarath farm. The main cost items (digester, pumps, generator, electrical systems, gas treatment) are based on supplier quotations; the remainder are estimates. Over-all accuracy will be within ±10%.

Table 40: Investment costs Nget Sovanarath farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	21,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	5,000	10	5%
Generator	19,000	5	10%
Electrical systems	20,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**76,000**	**N/A**	**N/A**
Contingencies	7,600	N/A	N/A
Pre-production financial costs	2,821	N/A	N/A
Total investment costs	**86,421**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 3,300 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 9,900 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at 974 US$; this is built up of accounts receivable (1,309 US$) minus accounts payable (335 US$).

7.7.3 Production costs

Table 41 shows the annual operating and production costs of the biogas system. Note that in the operating costs, maintenance of the generator takes up the largest part (47%), followed by staff costs (22%) and digester maintenance (10%). The remainder is maintenance for other equipment.

Table 41: Production costs Nget Sovanarath farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	3,120	3,120	3,120	3,120	3,120	3,120
Operating costs	**4,020**	**4,020**	**4,020**	**4,020**	**4,020**	**4,020**
Depreciation	8,598	8,598	8,598	8,598	8,598	8,598
Financing costs	5,643	4,514	3,386	2,257	1,129	0
Production costs	**18,261**	**17,132**	**16,004**	**14,875**	**13,747**	**12,618**

7.7.4 Revenues

Revenues from the biogas system concern diesel consumption reduction and sales to the local REE grid.

Table 42: Revenue Nget Sovanarath farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	78,563	0.10	7,856
Diesel reduction	litres	4,763	0.50	2,381
Total revenue	**US$**			**10,238**

7.7.5 Cash flow analysis

Table 43 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Net cash flows are negative during the load repayment period; from year 6 onward, cash flows are positive with the exception of year 10. Cumulative net cash flow does not become positive before the end of the project duration.

Table 43: Cash flow Nget Sovanarath farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	26,000	0	0	0	0	0	0
Debt financing	61,000	0	0	0	0	0	0
Short term financing	0	335	0	0	0	0	0
Inflow from operations	0	10,238	10,238	10,238	10,238	10,238	10,238
Total inflow	**87,000**	**10,573**	**10,238**	**10,238**	**10,238**	**10,238**	**10,238**
Increase fixed assets	83,600	0	0	0	0	22,000	0
Increase current assets	0	1,309	0	0	0	0	0
Operating costs	0	4,020	4,020	4,020	4,020	4,020	4,020
Corporate tax	2,821	5,643	4,514	3,386	2,257	1,129	2,821
Interest payable	0	12,200	12,200	12,200	12,200	12,200	0
Loan repayments	0	0	0	0	0	0	0
Total outflow	**86,421**	**23,172**	**20,734**	**19,606**	**18,477**	**39,349**	**4,020**
Net cash flow	**579**	**-12,599**	**-10,496**	**-9,368**	**-8,239**	**-29,111**	**6,218**
Cumulative	**579**	**-12,020**	**-22,517**	**-31,885**	**-40,124**	**-69,235**	**-63,017**

Corporate tax is 0 as total production costs (including depreciation) are higher than annual revenues.

Table 44 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.251 US$/kWh, in contrast to the tariff of 0.100 US$/kWh that is expected from the local REE.

Table 44: Indicators Nget Sovanarath farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.251
IRR	%	-5%
NPV	US$	-64,482
Simple Payback period	years	13.9

7.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 41 below.

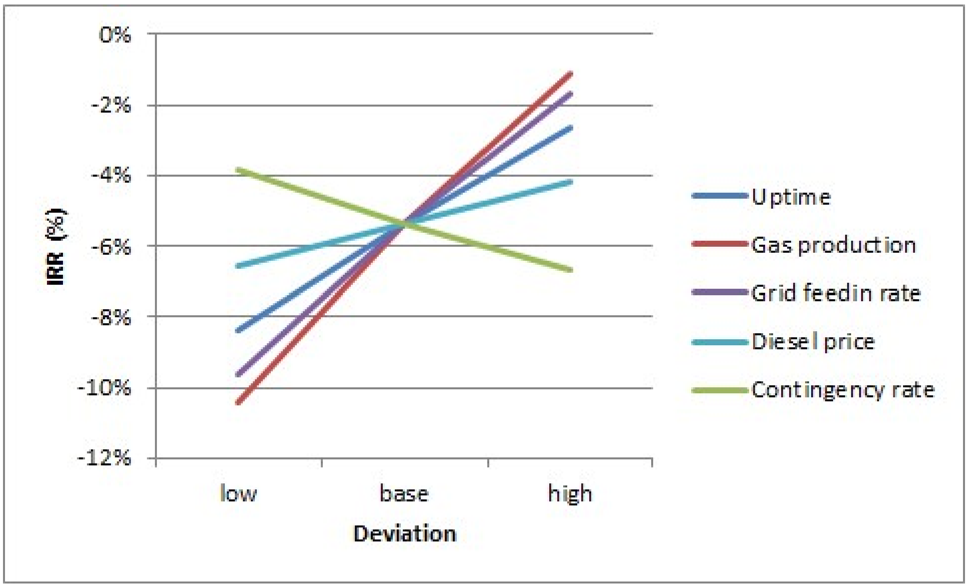

Figure 41: Sensitivity analysis Nget Sovanarath biogas project

The results show that variations in diesel price (±20%) and contingency rate (10±10%) have limited consequences, resulting in IRR changes below ±1.5% points. Generator availability changes result in IRR changes of 3% points; deviations in grid feed-in tariff (±20%) and gas production (±20%) have the largest consequences (IRR changes of ±4-5% points).

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%), increased diesel price (+20%) and lower investment costs (0% contingency rate) results in an IRR of 1%
- Reduced generator uptime (80%) and lower feed-in rate (-20%) result in an IRR of -13%
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%), lower feed-in tariff (-20%), higher contingency rate (20%), results in a payback period of 48 years.
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 7% (6.5 years payback period).

Increases in on-farm electricity demand have a moderate effect. If electricity demand would increase with 22,500 kWh – e.g. when all 3 stables would be closed, and fitted with fans and water curtains – IRR would increase to -3% (payback period 12 years).

Note that selecting a low-cost solution for the generator, and a 25% reduction in water consumption, will have insignificant effect on the project IRR.

7.8 Conclusions

The average biogas production potential at Nget Sovanarath farm is approx. 165 m^3/d, with fluctuations of ±100% due to the all-in, all-out system practiced. Electricity production potential is approx. 280 kWh/d on average (91,977 kWh/a). The project features a covered lagoon digester with a volume of 2,500 m^3 and a 40 kW (50 kVA) gas generator.

Total investment costs of the system is 86,421 US$. In the base case scenario, the Levelised Cost of Electricity is 0.226 which is well above the grid feed-in rate. The Simple Payback period is 13.9 years. The project economics are most sensitive to gas production rate and feed-in tariff, and least to diesel price and investment costs.

8 FEASIBILITY STUDY: EANG SOULENG

Table 45: Eang Souleng farm location and contact

Farm	Eang Souleng
Village	Rovieng
Commune	Romcheck
District	Banteay Srey
Province	Siem Reap
GPS	13.5297N, 103.9856E
Owner	Mrs. Eang Souleng 097 929 9988, 081 698 458

8.1 Introduction

The farm of Mrs. Eang Souleng is located in Siem Reap province, Banteay Srey district, some 10km south of the district capital Banteay Srey. The farm is a fattening farm, one of many farms working under contract for C.P. Cambodia, a large feed and livestock company. The farm has 2 stables with a holding capacity of 600 heads each, i.e. a total capacity of 1200 heads. The farm is located next to the farm of Te Sopheak (same size, see chapter 6) and two other – larger – pig farms (2400 and 7200 heads, respectively).

Figure 42: Map of Eang Souleng farm

The farm is part of the family business, which includes also an aluminium window frame construction company. The family recently took over the farm from its previous (first) owner who constructed the farm some 4 years ago.

8.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months from approx. 7kg to 100-120kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

Note that C.P. practices an "all in, all out" system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease.

Feeding is done with CP feed, following C.P. procedures. Feeding is increased gradually, from 0-1.5 kg/head/day in the first 70 days; then from 1.5 to 2.5 kg/head/day until 138 days. After that, feeding is stable at 2.5 kg/head/day.

The layout of the stables is as prescribed by C.P. Each stable has 26 pens, each holding 23 pigs. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4x1.5x0.15m = 0.9 m^3) are always filled with water, which is changed every day. Cleaning of the pens is also done every day.

8.3 Biogas feedstock

8.3.1 Manure and urine production

Average daily dung production is estimated at 0.94 tonnes per day. However, because of the "all in, all out" system and the animal feeding pattern, there is a large variation in dung availability. At the start of each cycle, when the farm houses small piglets, dung production will be negligible. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). After the stables have been cleared out, there is a period of 2-4 weeks where there is no dung production at all. Fresh dung production will thus vary between 0 and approx. 1.7 t/d. Total dry matter production (including solids from urine) will be approx. 0.36 t/d, varying between 0 and 0.72 t/d.

Urine production will also vary throughout the cycle, but is on average 3 m^3/d.

The dung, urine and cleaning water from each stable flow into a single pond located behind each stable (10x20m). There is no slurry removal; water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

8.3.2 Water consumption

Water for the Eang Souleng farm is pumped from a borehole on the farm site. Apart from drinking water, water consumption at the farm totals approx. 54 m^3/d (based on spot water flow measurements). It consists of the following components:

- Cleaning of the pens. This is done every day with a hose, which takes up to 1 hour. Total water consumption for the two stables is approx. 12 m^3/d.
- Refreshing the bath water. This is done every day after cleaning. Daily water consumption is approx. 42 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 1 m^3/d.

8.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 46 below.

Table 46: Total waste production at Eang Souleng farm

Source	Unit	average	minimum	maximum
Water	t/d	54	54	54
Dung (fresh)	t/d	0.9	0.0	1.9
Urine	t/d	3.0	0	6.0
Evaporation	t/d	1.0	1.0	1.0
Total waste water	t/d	57	53	61
DM content	%	0.6%	0.0%	1.2%

Waste production, 48 l/head/d, is significantly above the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d). A reduction of the water consumption (e.g. by closing off water when not in use, or using pressurized water for hosing) would somewhat reduce the required biogas system volume, and the energy consumption of water pumps.

8.3.4 Biogas and electricity production potential

Table 47 below gives an overview of the biogas and electricity production potential at Eang Souleng farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.5 kWh/m^3 (approx. 25% generator efficiency, due to small size). Annual electricity production potential, at 90% generator availability, would be 53,217 kWh/a.

Table 47: Biogas and electricity production potential at Eang Souleng farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	108	0	216
Total electricity	kWh/d	162	0	324
Total electricity (at 90% genset availability)	kWh/a	53,217		

8.4 Energy demand and supply

8.4.1 Energy demand

Energy demand at Eang Souleng farm is mainly related to water pumping. There is currently one pump that runs for approx. 5h/d for filling the drinking water tanks (2x10,000l) and for cleaning the stables. The water is taken from a borehole inbetween the stables. Daily diesel consumption is approx. 5 l/d. A second pump has already been installed, for pumping water from a second borehole, in combination with a drinking water treatment system.

Electricity consumption at the farm is negligible. There are four 3W LED bulbs in each stable that are used all night. There is also a small house in which the owner and her husband sleep every night. Before, the diesel engine of the pump was used for driving a 3kVA alternator for 3-

4 hours per day, consuming 1.5 l/d of diesel. Now there is a PV system (4 panels, estimated 1 kWp) with 400 Ah (12V) battery storage and a 1kW inverter. There is also a smaller panel on the house of the owner.

On the basis of fuel consumption, water pumping would consume some 12 kWh/day with the second pump installed this could increase somewhat, to approx. 20 kWh/d. Electricity consumption is estimated at 2 kWh/d, bringing total electricity demand at 22 kWh/d or 8,030 kwh/a. Electrical load would be approx. 3 kW during pumping, provided that the two pumps would not be run simultaneously.

8.4.2 Supply strategy

Disregarding the electricity that is currently supplied with the PV system, the on-site electricity demand is about 12% of the average production potential, and some 6% of the maximum production potential. Most of the energy would thus have to be supplied to a grid.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (216 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 24kW (30kVA) genset.

In periods of low biogas availability, the generator should run only for powering the water pump, and not (or as little as possible) for supplying to the grid. This will require some 20-30 m^3/d of gas; any biogas in storage can then cover a longer period of supplying own electricity demand. It is estimated that there would be sufficient gas for water pumping during 11 months per year, and for on-farm electricity consumption during 8 months per year.

8.5 System alternative

One possible system alternative would be to combine the waste resources of multiple farms, in order to achieve a larger scale – if sanitary regulations of C.P. would allow this (see section 2.3). In this case, collaboration with the neighbouring farm of Te Sopheak (see chapter 6) could be considered. There are other farms in the vicinity as well, but these do not participate in the project. The collaboration could result in a smaller fluctuation in dung availability, if the ”all-in, all-out” cycles of the two farms are out of phase. Also, the biogas could sustain a larger, more efficient, generator set. The result of this alternative will be presented in the sensitivity analysis (section 8.8.6).

8.6 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 20.4 t/a (511 tCO_{2eq} /a).
- Diesel substitution is 2,376 l/a (6 tCO_{2eq} /a).
- Grid electricity substitution is 23,324 kWh/a (15 tCO_{2eq}/a)[19].
- Total GHG reduction is thus 532 tCO_{2eq} /a.

[19] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as 1) part of the electricity is used on the farm, therby substituting diesel rather than replacing grid electricity; 2) generator availability is 90%; and 3) grid demand (by EDC) is only 50% of the time

8.7 Biogas plant description

8.7.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (61 m^3/d) and the recommended retention time of 30 days, digester volume is set at 1,900 m^3. Dimensions of the lagoon will be approx. 45x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 55x25m. Note that these dimensions are provisional and will be set during final design.

Waste water will flow from the stables through canals into a central sedimentation tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

8.7.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 24 kW (30 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid.

Any excess biogas will be burnt off with a flare.

8.8 Financial analyses

8.8.1 Basic parameters

Table 48 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

Table 48: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on indications from EDC

8.8.2 Investment costs

Table 49 below gives an overview of the investment costs of the biogas system at Eang Souleng farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 49: Investment costs Eang Souleng farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	18,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	5,000	10	5%
Generator	14,000	5	10%
Electrical systems	8,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**56,000**	**N/A**	**N/A**
Contingencies	5,600	N/A	N/A
Pre-production financial costs	2,081	N/A	N/A
Total investment costs	**63,681**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 2,000 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 7,000 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at 164 US$; this is built up of accounts receivable (389 US$) minus accounts payable (225 US$).

8.8.3 Production costs

Table 50 shows the annual operating and production costs of the biogas system in the first 6 years. Note that in the operating costs, staff costs take up the largest part (33%), followed by maintenance of the generator (32%) and digester maintenance (13%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 8.8.1), these will remain 0 from year 6 onwards.

Table 50: Production costs Eang Souleng farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	1,795	1,795	1,795	1,795	1,795	1,795
Operating costs	**2,695**	**2,695**	**2,695**	**2,695**	**2,695**	**2,695**
Depreciation	6,398	6,398	6,398	6,398	6,398	6,398
Financing costs	4,163	3,330	2,498	1,665	833	0
Production costs	**13,256**	**12,423**	**11,591**	**10,758**	**9,926**	**9,093**

8.8.4 Revenues

Revenues from the biogas system concern diesel consumption reduction and sales to the grid.

Table 51: Revenue Eang Souleng farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	23,324	0.10	2,332
Diesel reduction	litres	2,376	0.50	1,188
Total revenue	**US$**			**3,520**

EDC has indicated to be willing to consider a price level below 0.10 US$/kWh, but that they will only purchase electricity during the dry season (January-May/June). The quantity of electricity sold is therefore set at 50% of the potential (see section 8.3.4).

8.8.5 Cash flow analysis

Table 52 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Throughout the loan repayment period, cash flows are negative; only from year 6 onwards there are small positive cash flows, with the exception of year 10 (US$ -21,175). Cumulative cash flow does not become positive during the 15 year project period.

Table 52: Cash flow Eang Souleng farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	19,000	0	0	0	0	0	0
Debt financing	45,000	0	0	0	0	0	0
Short term financing	0	225	0	0	0	0	0
Inflow from operations	0	3,520	3,520	3,520	3,520	3,520	3,520
Total inflow	**64,000**	**3,745**	**3,520**	**3,520**	**3,520**	**3,520**	**3,520**
Increase fixed assets	61,600	0	0	0	0	16,500	0
Increase current assets	0	389	0	0	0	0	0
Operating costs	0	2,695	2,695	2,695	2,695	2,695	2,695
Corporate tax	0	0	0	0	0	0	0
Interest payable	2,081	4,163	3,330	2,498	1,665	833	0
Loan repayments	0	9,000	9,000	9,000	9,000	9,000	0
Total outflow	**63,681**	**16,262**	**15,025**	**14,193**	**13,360**	**29,028**	**2,695**
Net cash flow	**319**	**-12,501**	**-11,505**	**-10,672**	**-9,840**	**-25,507**	**825**
Cumulative	**319**	**-12,183**	**-23,687**	**-34,359**	**-44,199**	**-69,706**	**-68,881**

Table 53 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.564 US$/kWh, in contrast to the tariff of 0.10 US$/kWh that EDC is offering, and the normal grid tariff of 0.15 US$/kWh.

Table 53: Indicators Eang Souleng farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.564
IRR	%	N/A
NPV	US$	-70,651
Simple Payback Period	years	77 years

8.8.6 Sensitivity analysis

The indicators in Table 53 show a project with poor economic outlook. There are many factors contributing to this, but the most important are the low energy demand on the farm, and the restricted demand of EDC. A change in the demand situation should therefore be seen as a first prerequisite for project potential:

- Grid supply throughout the year would result in a project IRR of -13% and a payback period of 24 years.
- Increasing on-farm electricity demand with 15,000 kWh/a (e.g. by applying closed stable systems) would result in a project IRR of -15% and a payback period of 29 years.
- A combination of the two would result in an IRR of -10% and a payback period of 19 years.

The sensitivity to other variables will be tested under the assumption that electricity can be supplied to the grid throughout the year. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM; in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 43 below.

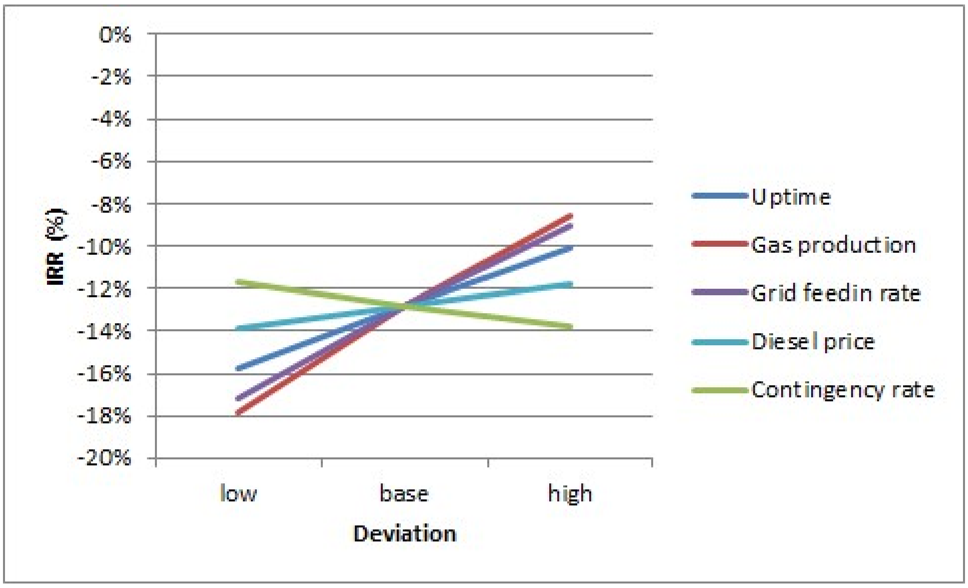

Figure 43: Sensitivity analysis Eang Souleng biogas project

The results show that sensitivity to diesel price (±20% variations) and investment costs (contingency rate 10±10%) are limited; deviations to the standard values result in IRR changes of approx. 1% point. Sensitivity to generator uptime (90±10%) is slightly higher, resulting in IRR changes of approx. 3% points. Sensitivity to grid feed-in tariff (±20%) and gas production (±20%) is high; deviations result in IRR changes of 4-5% points.

Note that selecting another generator or reducing water consumption (see section 8.8.2) has little effect on project viability. Choosing a modified diesel engine can reduce payback period from 24 to 21 years and result in an IRR of -12%. A water reduction of 25% results in a smaller digester unit but the over-all investment cost reduction is limited. Payback period changes to 23, IRR to -12%.

The system alternative mentioned in section 8.5 has a positive effect on project economics but does not lead to a viable business case. It would result in a 3,600 m^3 digester with a 50 kVA gas generator. Investment costs increase to approx. 87,000 US$, and IRR to -10% (Simple Payback Period of 20 years). As indicated, this would be under the assumption that this mode of collaboration would be possible within the context of C.P. contract farming.

8.9 Conclusions

The average biogas production potential at Eang Souleng farm is approx. 108 m^3/d, with fluctuations of ±100% due to the all-in, all-out system practiced. Electricity production potential is approx. 162 kWh/d on average (53,217 kWh/a). The project features a covered lagoon digester with a volume of 1,900 m^3 and a 24 kW (30 kVA) gas generator. Total investment is 63,681 US$.

The scale of the system is limited, and with the seasonal demand of electricity by EDC the Levelised Cost of Electricity is 0.508 US$/kWh as compared to a possible feed-in rate of 0.10 US$/kWh and an electricity tariff of 0.15 US$/kWh. Continuous grid supply (also during rainy season) and/or increased on-site electricity demand should be considered first prerequisites for developing project potential.

9 FEASIBILITY STUDY: CHREN VORN

Table 54: Chren Vorn farm location and contact

Farm	Chren Vorn
Village	Chheuteal
Commune	Tbaeng
District	Kampong Svay
Province	Kampong Thom
GPS	12.8707N, 104.7844E
Owner	Mr. Chren Vorn 012 484 377

9.1 Introduction

The farm of Mr. Chren Vorn is located in Kampong Thom province, Kampong Svay district, some 30km North of the town of Krong Stueng Saen. The farm is a fattening farm, one of many farms working under contract for C.P. Cambodia, a large feed and livestock company. The farm has 2 clusters of 2 stables (total 4 stables) with a holding capacity of 600 heads each, i.e. a total capacity of 2,400 heads.

Figure 44: Map of Chren Vorn farm

9.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of up to 5 months from approx. 5kg to 100kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

Note that C.P. practices an “all in, all out” system, but other than at commonly applied, at the Chren Vorn farm it is applied to the clusters of stables independently. This means that for each cluster, all the finished pigs are collected at the end of a fattening cycle, to be replaced with piglets after 2-4 weeks. However, this is not done for both clusters at the same time.

Feeding is done with CP feed, following C.P. procedures. Feeding is increased gradually, from 0-1.5 kg/head/day in the first 70 days; then from 1.5 to 2.5 kg/head/day until 138 days. After that, feeding is stable at 2.5 kg/head/day.

The layout of the stables is as prescribed by C.P. Each stable has 26 pens, each holding 23 pigs. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4x1.5x0.15m = 0.9 m^3) are always filled with water, which is changed every day. Solid dung is removed from the pens every day; hosing done of the pens is done twice per week.

9.3 Biogas feedstock

9.3.1 Manure and urine production

Average daily dung production is estimated at 1.9 tonnes per day. There is a large variation in dung availability, as four times per year half the animals in the farm are replaced with piglets whose dung production is initially very low. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). Fresh dung production will thus vary between 0.9 and approx. 2.8 t/d. Total dry matter production (including solids from urine) will be approx. 0.72 t/d, varying between 0.36 and 1.08 t/d.

Urine production will also vary throughout the cycle, but is on average 6 m^3/d.

The dung, urine and cleaning water from the two stables on the eastern part of the premises flow into a single pond (15x50x4m) located behind the stables; the two stables on the west part of the premises each have their own pond (10x40x4m). From the large pond, slurry is once per year pumped into the rice field; the other ponds are frequently emptied into the public drainage system.

9.3.2 Water consumption

Water for the Chren Vorn farm is pumped from a borehole on the farm site. Apart from drinking water, water consumption at the farm totals approx. 95 m^3/d (based on spot water flow measurements). It consists of the following components:

- Cleaning of the pens. This is done twice per week, which takes approx. 2 hours per stable and which consumes 9 m^3 of water for each stable. Total average water consumption for the four stables is approx. 10 m^3/d.
- Refreshing the bath water. This is done every day after cleaning. Daily water consumption for the four stables is approx. 84 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 2 m^3/d.

9.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 55 below.

Table 55: Total waste production at Chren Vorn farm

Source	Unit	average	minimum	maximum
Water	t/d	95	95	95
Dung (fresh)	t/d	1.9	0.9	2.8
Urine	t/d	6	3	9
Evaporation	t/d	2.0	2.0	2.0
Total waste water	t/d	100	96	104
DM content	%	0.7%	0.4%	1.0%

Waste production (42 l/head/day) is just below the average found in the sector (43 l/head/d) but significantly above the average found in e.g. Vietnam (approx. 30 l/head/d). A reduction of the water consumption (e.g. by closing off water when not in use, or using pressurized water for hosing) would somewhat reduce the required biogas system volume, and the energy consumption of water pumps.

Figure 45: Stables and pond at Chren Vorn farm

Figure 46: Water flow measurements

9.3.4 Biogas and electricity production potential

Table 56 below gives an overview of the biogas and electricity production potential at Chren Vorn farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency, due to small size). Annual electricity production potential would be 120,625 kWh/a.

Table 56: Biogas and electricity production potential at Chren Vorn farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	216	108	324
Total electricity	kWh/d	367	184	551
Total electricity (at 90% genset availability)	kWh/a	120,625		

9.4 Energy demand and supply

9.4.1 Energy demand

Energy demand at Chren Vorn farm is mainly related to water pumping. There are 2 electric (immersion) pumps, one for each cluster of 2 stables. The pumps are operated for approx. 3 h/d, for pumping of drinking water (5000 l tank at each stable), bath water (basin) and cleaning water. The water pump load was measured at approx. 1.7 kWe (0.95 power factor), so total electricity consumption for water pumping would be some 10 kWh/d.

Electricity for water pumping is produced with two generators, one at each cluster: 14hp engine with a 7.5kW alternator, and a 20hp engine with a 10kW alternator. Total diesel consumption for water pumping is approx. 10 l/d. Note that when the piglets are small, the pumps run only every other day.

An additional 150 l/a of diesel is used for pumping the contents of the ponds into the rice fields, once per year.

Electricity consumption at the farm is negligible. There are four 5W lamps in each stable that are used all night. There are four lamps elsewhere on the farm (entrance, kitchen, toilet and house), and a television set. The electricity is produced using a PV set (estimated 1.5 kWp) and a small inverter. Total electricity demand for lighting and TV is estimated at maximum 2 kWh/d.

The farm manager indicated that there is an interest in starting the production of drinking water, when there would be sufficient power for this. However, there are no ideas yet of the scale of water production, or the potential energy demand.

On the basis of the above, farm electricity demand is estimated at 12 kWh/d, or 4,380 kWh/a. Average load during water pumping would be approx. 3.5 kW, when both water pumps are running simultaneously.

9.4.2 Supply strategy

Disregarding the electricity that is currently supplied with the PV system, the on-site electricity demand is about 3% of the average production potential, and only 2% of the maximum production potential. Most of the energy would thus have to be supplied to a grid.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (324 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 40kW (50kVA) genset.

There will be biogas available for electricity production throughout the year, but with variations in daily quantity. In periods of high biogas availability, the generator can run for approx. 16 h/d; in periods of low gas availability it can run for 8 hours per day, or longer at reduced output, if the grid demand so requires.

9.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 40.8 t/a (1021 tCO_{2eq} /a).
- Diesel substitution is 3,285 l/a (9 tCO_{2eq} /a).
- Grid electricity substitution is 116,683 kWh/a (77 tCO_{2eq}/a)[20].
- Total GHG reduction is thus 1,107 tCO_{2eq} /a.

[20] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as part of the electricity is used on the farm, thereby substituting diesel rather than replacing grid electricity

9.6 Biogas plant description

9.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (104 m^3/d) and the recommended retention time of 30 days, digester volume is set at 3,100 m^3. Dimensions of the lagoon will be approx. 65x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 75x25m. Note that these dimensions are provisional and will be set during final design.

Waste water from each stable will flow through a canal into a sedimentation tank (one per cluster of two stables). It will be pumped from the sedimentation tanks, though underground pipes, into a central collection tank, from where it is pumped into the digester. A circulation pump will be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

9.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 40 kW (50 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid through an 8km MV line.

Any excess biogas will be burnt off with a flare.

9.7 Financial analyses

9.7.1 Basic parameters

Table 57 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

Table 57: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

9.7.2 Investment costs

Table 58 below gives an overview of the investment costs of the biogas system at Chren Vorn farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 58: Investment costs Chren Vorn farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	23,000	15	2%
Pumps	3,000	5	5%
Structures	11,000	20	2%
Gas treatment	5,000	10	5%
Generator	19,000	5	10%
Electrical systems	88,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**154,000**	**N/A**	**N/A**
Contingencies	15,400	N/A	N/A
Pre-production financial costs	5,689	N/A	N/A
Total investment costs	**175,089**	**N/A**	**N/A**

The table shows particularly high costs for electrical systems; this is mainly due to the costs of extending the MV grid to the farm (8km). If the project would be implemented in the future, when this grid extension would already be in place, the investment costs would be approx. half.

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with 6,600 US$.

- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with 9,900 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at some 1,475 US$; this is built up of accounts receivable (1,945 US$) minus accounts payable (470 US$).

9.7.3 Production costs

Table 59 shows the annual operating and production costs of the biogas system during the first 6 years of the project. Note that in the operating costs, maintenance of the generator takes up the largest part (34%), followed by maintenance of the electrical systems (31%) and staff costs (16%). The remainder is maintenance for other equipment.

Table 59: Production costs Chren Vorn farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	4,740	4,740	4,740	4,740	4,740	4,740
Operating costs	**5,640**	**5,640**	**5,640**	**5,640**	**5,640**	**5,640**
Depreciation	14,502	14,502	14,502	14,502	14,502	14,502
Financing costs	11,378	9,102	6,827	4,551	2,276	0
Production costs	**31,519**	**29,244**	**26,968**	**24,693**	**22,417**	**20,142**

9.7.4 Revenues

Revenues from the biogas system concern diesel consumption reduction and sales to the local REE grid.

Table 60: Revenue Chren Vorn farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	116,683	0.100	11,668
Diesel reduction	litres	3,285	0.50	1,643
Total revenue	**US$**			**13,311**

9.7.5 Cash flow analysis

Table 61 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Throughout the loan repayment period, cash flows are negative; only from year 6 onwards there are small positive cash flows, with the exception of year 10 (because of reinvestment). Cumulative cash flow is not positive before the end of the project period.

Corporate tax is 0 as total production costs (including depreciation) are higher than annual revenues.

Table 62 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.344 US$/kWh, in contrast to the expected feed-in tariff of 0.100 US$/kWh.

Table 61: Cash flow Chren Vorn farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	53,000	0	0	0	0	0	0
Debt financing	123,000	0	0	0	0	0	0
Short term financing	0	470	0	0	0	0	0
Inflow from operations	0	13,311	13,311	13,311	13,311	13,311	13,311
Total inflow	**176,000**	**13,781**	**13,311**	**13,311**	**13,311**	**13,311**	**13,311**
Increase fixed assets	169,400	0	0	0	0	24,200	0
Increase current assets	0	1,945	0	0	0	0	0
Operating costs	0	5,640	5,640	5,640	5,640	5,640	5,640
Corporate tax	0	0	0	0	0	0	0
Interest payable	5,689	11,378	9,102	6,827	4,551	2,276	0
Loan repayments	0	24,600	24,600	24,600	24,600	24,600	0
Total outflow	**175,089**	**43,562**	**39,342**	**37,067**	**34,791**	**56,716**	**5,640**
Net cash flow	**911**	**-29,781**	**-26,031**	**-23,756**	**-21,480**	**-43,405**	**7,671**
Cumulative	**911**	**-28,870**	**-54,901**	**-78,657**	**-100,137**	**-143,542**	**-135,871**

Table 62: Indicators Chren Vorn farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.344
IRR	%	-8%
NPV	US$	-143,267
Payback period	years	22.8

9.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 47 below.

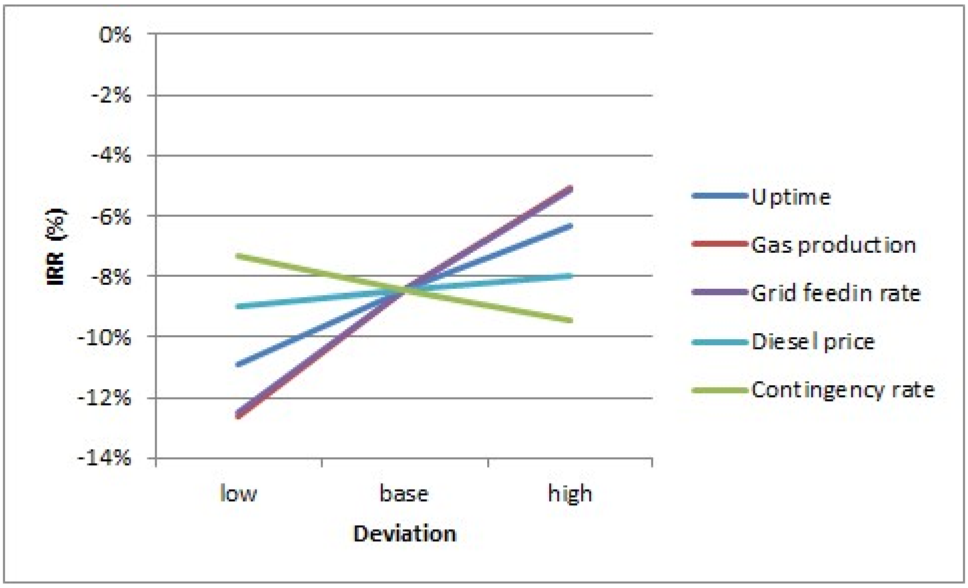

Figure 47: Sensitivity analysis Chren Vorn biogas project

The results show that variations in diesel price (±20%) have little effect on the project economics, leading to variations in IRR of just 0.5% points. Contingency rate deviations (10±10%) also have limited consequences. The project economics are most sensitive to deviations of the feed-in tariff and the gas production; variations of ±20% lead to IRR changes of approx. 4% points.

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20) and higher generator uptime (100%) results in an IRR of -3% (14.8 year payback period)
- Reduced generator uptime (80%) and lower feed-in rate (-20%) result in an IRR of -15%
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%), lower feed-in tariff (-20%), higher contingency rate (20%), results in a payback period of 90 years.
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 2% (10 years payback period).

Increases in on-farm electricity demand have a moderate effect. If electricity demand would increase with 30,000 kWh – e.g. when all 4 stables would be closed, and fitted with fans and water curtains – IRR would increase to -7% (payback period 19 years).

The omission of the MV grid – e.g. considering implementation of the project only when the MV has reached the farm – would have the highest effect: it would reduce Investment costs with 88,000 US$, and raise the project IRR to 1% (10 year payback period).

Note that selecting a low-cost solution for the generator, and a 25% reduction in water consumption, will have insignificant effect on the project IRR.

9.8 Conclusions

The average biogas production potential at Chren Vorn farm is approx. 216 m^3/d, with fluctuations of ±50% as the all-in, all-out system practiced is practices for the two clusters of stables, separately. Electricity production potential is approx. 367 kWh/d on average (120,625 kWh/a). The project features a covered lagoon digester with a volume of 3,100 m^3 and a 40 kW (50 kVA) gas generator.

Total investment costs of the system is 175,089 US$. In the base case scenario, the Levelised Cost of Electricity is 0.344 which is well above the grid feed-in rate and the expected electricity purchase price. The project economics are little sensitive to diesel price fluctuations, but highly sensitive to grid feed-in tariff and gas production.

10 FEASIBILITY STUDY: BVB INVESTMENT CORPORATION

Table 63: BVB Investment Corporation farm location and contact

Farm	BVB Investment Corporation
Village	La Ak
Commune	Kampong Thma
District	Santuk
Province	Kampong Thom
GPS	12.5745N, 105.1722E
Manager	Mr. Heam Sokha 092 907 717

10.1 Introduction

BVB Investment Corporation is part of the BVB group of companies which are active in the field of agriculture and agro-processing, including rice production, rice processing, pig rearing and animal feed production. The pig farm of BVB Investment Corporation is located in Kampong Thom province in central Cambodia, some 25 km east of the town of Krong Stueng Saen. It is a large farm, featuring both pig breeding and pig fattening; the average number of animals is approx. 16,000 heads. The numbers of animals and the variation therein are shown in Table 64 below.

Figure 48: Map of BVB Investment Corporation pig farm

The farm has a total of 33 stables: 22 for fattening pigs, 10 for sows and 1 for boar. The company aims to increase its capacity, specifically to increase the number of sows to approx. 5,000 and the production of piglets to 6,000 per month (from 2,200-2,300 heads per month today). Depending on market developments, additional fattening capacity will be added as well. The extension will mean the construction of additional stables on the east side of the premises.

10.2 Farm operation

The farm breeds its own pigs for fattening: production of piglets is about 2,200-2,300 per month. Depending on the market demand, a percentage of this is sold (on average 20-25%), and the remainder is fattened. Fattening is done in a period of approx. 5 months, depending on the meat price around the time of finishing. During this period the animals are raised from a weight of approx. 8kg to 80 kg per head.

Average feed consumption is approx. 600 kg/month. Pig feeding is done according to schedule; during the fattening process, fattening pigs consume some 200-230 kg/head. The feed is produced by the BVB feed processing factory some 20km away and collected each day by truck.

The stables of the fattening pigs (16x72m) each have 32 pens, holding 25 animals each. Each pen has its own individual bath (approx. 4.5x1.2x0.1m) which is cleaned every day. The pens are hosed down once per two days. Stables of the sows (15x75m) have slatted floors, allowing the manure and urine to pass through. The boar are kept in a smaller stable (15x45m); this is a closed stable that is fitted with a ventilation system.

10.3 Biogas feedstock

10.3.1 Manure and urine production

Table 64 gives an overview of the production of dung, urine and dry matter therein. The pig slurry from all stables flows through a system of pipes and canals to a central collection point, from where it enters the first of a series of 6 ponds (each 10x25x5m) located in the south of the farm premises. There is no slurry removal; water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

Table 64: Average livestock, dung and urine production at BVB Investment farm

Animal	Heads	Variation	Fresh dung (t/d)	Urine (m^3/d)	Total DM (t/d)
Fattening pigs	14,000	±30%	10.9	35.0	4.20
Sows	1,800	±10%	2.8	9.0	1.08
Boar	35	N/A	0.1	0.2	0.03
Total	**15,835**		**13.8**	**44.2**	**5.3**

Note that the future capacity expansion could result in the additional production of some 9 t/d of dung and 29 t/d of urine, under the assumption that the number of sows would increase with 3,200 heads and the average number of fattening pigs with 5,000 heads.

10.3.2 Water consumption

Water for the BVB farm is pumped from two boreholes into a 500 m^3 reservoir. From there it is pumped into a 36 m^3 water tower, in order to provide water pressure. On the basis of spot water flow measurements, total water consumption is estimated at 416 m^3 per day:

- Changing of bathing water in fattening and boar stables: 358 m^3/d (15.6 m^3/d per stable in 23 stables, daily)
- Cleaning of pens with hose: 52 m^3/d (4.5 m^3 per stable in 23 stables, once every two days)
- Cleaning sow stables with high pressure water: 7 m^3/d (0.7 m^3/stable in 10 stables, daily)

Water evaporation is estimated at 0.5 m^3/d/stable or 16.5 m^3/d in total.

10.3.3 Total waste production

Total waste production is shown in Table 65 below. The quantity (29 l/head/day) is among the lowest encountered in the sector.

Table 65: Total waste production at BVB Investment Corporation farm

Source	Unit	average	minimum	maximum
Water	t/d	416	416	416
Dung (fresh)	t/d	13.8	10.3	17.4
Urine	t/d	44.2	30.9	57.4
Evaporation	t/d	16.5	16.5	16.5
Total slurry	t/d	458	441	475
DM content	%	1.2%	0.9%	1.4%

Waste production (29 l/head/day) is significantly below the average found in the sector (43 l/head/d) and just below the average found in e.g. Vietnam (approx. 30 l/head/d).

10.3.4 Biogas and electricity production potential

Table 66 below gives an overview of the biogas and electricity production potentials of the different sources of dung, as well as the variation therein. Biogas production is based on 300 m^3/tDM for pig slurry. Electricity production is based on 1.9 kWh/m^3 (approx. 33% generator efficiency). Annual electricity production potential would be 1,104,329 kWh/a.

Table 66: Biogas and electricity production potential at BVB Investment Corporation farm

Source	Unit	Average	Minimum	Maximum
Total biogas	**m^3/d**	**1,592**	**1,182**	**2,003**
Total electricity	kWh/d	3,026	2,246	3,805
Total electricity (at 90% genset availability)	kWh/a	120,625		

With the farm capacity extension as indicated in section 10.3.1, average biogas potential would increase with some 1000 m^3/d (64%), and electricity production potential with some 2000 kWh/d.

Figure 49: Outside BVB fattening pig stable

Figure 50: Slurry pond at BVB

10.4 Energy demand and supply

10.4.1 Energy demand

At present, energy consumption on the farm site consists of the following:

- Water pumping, from the boreholes into the reservoir with two immersion pumps, and into the water tower with a third pump.
- Several small pumps (mobile units) are used for cleaning the sow stables and (irregularly) for high pressure cleaning in the fattening pig stables.
- Lighting: 12 CFL (25W) in the nursery stables, which are used all night, plus approx. 30 outside lamps for security.
- 11 worker quarters, each with a lamp and a table fan, and 7 TV sets, used for 4 h/d.
- 4 large fans (measured 1.3kVA) in the closed boar stable with water curtain, for keeping the stable cool, used some 4h/d.

Electricity is produced with two diesel generators, a 60kVA and a 150kVA set. They are used intermittently, according to the following schedule:

- From 7-11am, the 150kVA generator
- From 11am-1:30pm, the 60kVA generator
- From 1:30pm-3:30pm, the 150kVA generator
- From 6pm-7am, the 60kVA generator

Figure 51: Pump for water pressurisation

Figure 52: Generators at BVB

Early 2015, the grid was extended to less than 2km from the farm. Although farm management is sceptical about its reliability, grid power will be substantially cheaper than electricity from diesel. As the farm has their current diesel generators as backup, reliability may be a secondary concern, and it is likely that it will be a matter of time before the farm will be connected to the grid.

Figure 53 below shows the load curve as measured on 18-19 September 2015. It concerns 1-minute averages; actual peak loads are approx. 60-70 kVA. Total daily electricity consumption is approx. 440 kWh; typical diesel consumption for electricity production is 4-5 t/month. Production efficiency is on average 2.49 kWh/l of diesel which is within the expected range for this generator capacity and loading rates.

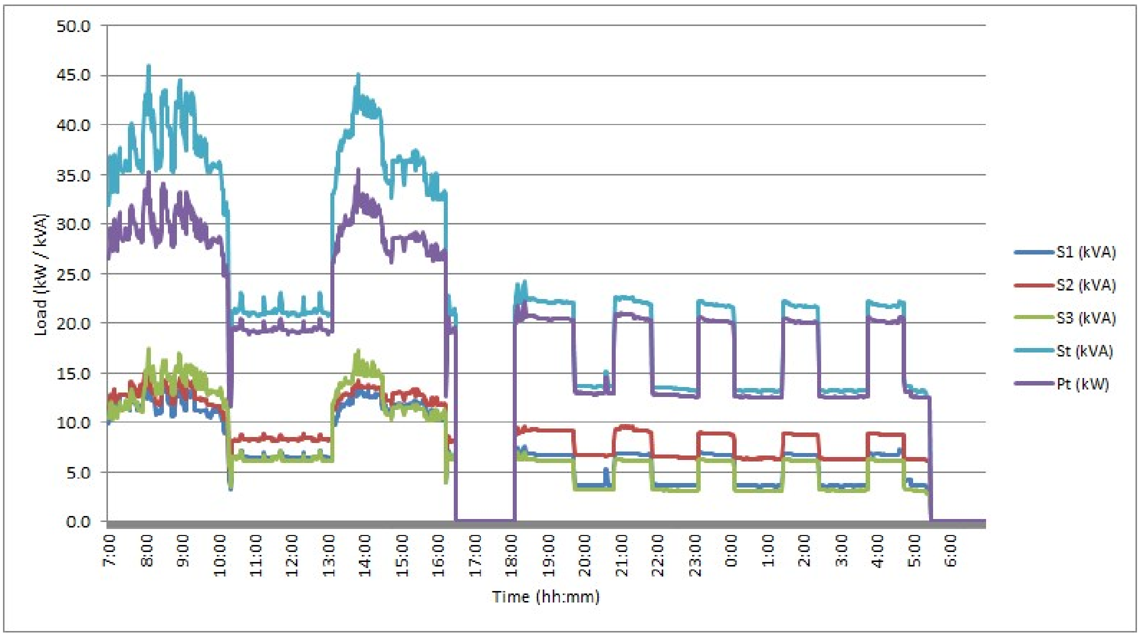

Figure 53: Load curve at BVB Investment Corporation pig farm

In the future, the following demand increases can be expected:

- Farm management is considering a switch from open stable to closed stables, if there would be an economical means of producing the required electricity. This means that existing stables would be fitted with ventilation systems and water curtains similar to those in the boar stable, running for approx. 4 hours per day. Total additional consumption would be approx. 581 kWh/d, on top of the existing 440 kWh/d.
- The planned farm capacity increase will result in a near doubling of the number of stables; electricity demand would increase with some 60%.

An overview of current and future electricity demand is provided in Table 67 below.

Table 67: Present and future electricity demand at BVB Investment Corporation farm

Source	Consumption (kWh/d)	Consumption (kWh/a)	Peak load (kW)
Present demand	440	160,600	40
Additional demand closed stables	581	211,992	160
Present demand + closed stables	1,021	372,592	200
Farm capacity extension	1,633	596,147	320

Note that farm management expressed its interest in supplying electricity to the BVB feed factory, some 20km away. However, the load of this factory is high (estimated at 300 kVA minimum) which, in combination with the distance, would result in high infrastructure costs. At the same time, consumption is low (at present some 1,700 kWh/month) making investment cost recovery impossible. Also, the national grid has arrived at the factory site which will bring down the reference price level for electricity.

10.4.2 Supply strategy

The electricity demand – including future demand from the closed barns - at the BVB farm amounts to approx. 34% of the total electricity production potential. Two production scenarios can be distinguished: i) production of captive power only, and ii) full utilisation of the biogas potential, supplying excess electricity to the grid.

Captive power

In the case of captive power production, the biogas is used for meeting the on-farm electricity demand only. A smaller digester is required as biogas demand is limited. A genset of 200 kVA is proposed, which would produce some 1,000 kWh/d. Peak load would occur around mid-day, when the cooling systems of the closed barns would be running full load.

Full production

In the case of full production, all biogas is converted to electricity, and the electricity not used on-farm would be fed into the grid. For this purpose, a 240kW (300kVA) gas engine is proposed. It would run for a maximum number of hours (e.g. 20 hours per day). It could cover the full load of the farm (including the closed stables) and supply excess power in early morning, evening and night time.

10.5 GHG emission reductions

Greenhouse gas reductions from this project, for the ***full production*** scenario, is as follows:

- Methane emission reduction is 269.5 t/a (6,738 tCO_{2eq} /a).
- Diesel substitution is 57,971 l/a (155 tCO_{2eq} /a).
- Grid electricity substitution is 870,556 kWh/a (572 tCO_{2eq}/a)[21].
- Total GHG reduction is thus 7,465 tCO_{2eq} /a.

For the ***captive power*** scenario, it is as follows:

- Methane emission reduction is 90.9 t/a (2,273 tCO_{2eq} /a).
- Diesel substitution is 57,971 l/a (155 tCO_{2eq} /a).
- Grid electricity substitution is 211,992 kWh/a (139 tCO_{2eq}/a)[22].
- Total GHG reduction is thus 2,568 tCO_{2eq} /a.

10.6 Biogas plant description

10.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

[21] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the eectricity production potential as part of the electricity is used on the farm, thereby substituting diesel rather than replacing grid electricity

[22] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the eectricity production potential as part of the electricity is used on the farm, thereby substituting diesel rather than replacing grid electricity

In the ***full production scenario***, the maximum daily amount of waste water (475 m^3/d) and the recommended retention time of 30 days result in a digester volume of 14,200 m^3. Dimensions of the lagoon will be approx. 90x35x6 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 100x45m. In the ***captive power*** scenario, the maximum daily electricity demand that must be met is 1,021 kWh/d, requiring 537 m^3/d of biogas resulting in a digester of 4,700 m^3 volume. Dimensions would be approx. 70x20x5 metres.

At present, waste water already flows from each stable to a central collection point. At this point, it will enter a sedimentation tank from where it will be pumped into the digester. A circulation pump will be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as done currently.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

10.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 200 kW (250 kVA) or 240 kW (300 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

In the ***full power scenario***, grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid through an MV line (approx. 1km).

Any excess biogas will be burnt off with a flare.

10.7 Financial analyses

10.7.1 Basic parameters

Table 68 shows the basic parameters used in the financial calculations. Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

Table 68: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

10.7.2 Investment costs

Table 69 and Table 70 below gives an overview of the investment costs of the biogas system at BVB Investment Corporation farm, in the ***full production*** and the ***captive power*** scenarios. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 69: Investment costs BVB Investment Corp farm biogas system (full production)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	67,000	15	2%
Pumps	2,000	5	5%
Structures	10,000	20	2%
Gas treatment	11,000	10	5%
Generator	54,000	5	10%
Electrical systems	26,000	15	2%
Engineering and installation	10,000	15	0%
Sub-total	**180,000**	**N/A**	**N/A**
Contingencies	18,000	N/A	N/A
Pre-production financial costs	6,614	N/A	N/A
Total investment costs	**204,614**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 13,200 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 29,700 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at some 10,000 US$; this is built up of accounts receivable (10,976 US$) minus accounts payable (976 US$).

Table 70: Investment costs BVB Investment Corp farm biogas system (captive power)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	29,000	15	2%
Pumps	2,000	5	5%
Structures	10,000	20	2%
Gas treatment	9,000	10	5%
Generator	49,000	5	10%
Electrical systems	0	15	2%
Engineering and installation	5,000	15	0%
Sub-total	**104,000**	**N/A**	**N/A**
Contingencies	10,400	N/A	N/A
Pre-production financial costs	4,024	N/A	N/A
Total investment costs	**118,424**	**N/A**	**N/A**

Investment costs reductions in the ***captive power*** scenario include the following:

- A 25% water reduction could reduce investment costs with some 4,400 US$.
- Using a modified diesel engine would reduce investment costs with some 26,400 US$.

Net working capital would be negative, consisting of only accounts payable with a value of 819 US$.

10.7.3 Production costs

Table 71 shows the annual operating and production costs of the biogas system in the ***full production*** scenario. Note that in the operating costs, maintenance of the generator takes up the largest part (46%), followed by staff costs (31%) and digester maintenance (11%). The remainder is maintenance for other equipment.

Table 71: Production costs BVB Investment Corp farm biogas system (full production)

Item / Year	1	2	3	4	5	6
Staff	3,600	3,600	3,600	3,600	3,600	3,600
Maintenance	8,110	8,110	8,110	8,110	8,110	8,110
Operating costs	**11,710**	**11,710**	**11,710**	**11,710**	**11,710**	**11,710**
Depreciation	21,633	21,633	21,633	21,633	21,633	21,633
Financing costs	13,228	10,582	7,937	5,291	2,646	0
Production costs	**46,571**	**43,925**	**41,280**	**38,634**	**35,989**	**33,343**

Annual production costs in the ***captive power*** scenario are shown in Table 72 below. They are approx. 25% lower than in the full production scenario. Generator maintenance remains the largest cost item (50%) followed by staff costs (37%).

Table 72: Production costs BVB Investment Corp farm biogas system (captive power)

Item / Year	1	2	3	4	5	6
Staff	3,600	3,600	3,600	3,600	3,600	3,600
Maintenance	6,230	6,230	6,230	6,230	6,230	6,230
Operating costs	**9,830**	**9,830**	**9,830**	**9,830**	**9,830**	**9,830**
Depreciation	15,253	15,253	15,253	15,253	15,253	15,253
Financing costs	8,048	6,438	4,829	3,219	1,610	0
Production costs	**33,131**	**31,521**	**29,912**	**28,302**	**26,693**	**25,083**

10.7.4 Revenues

Revenues from the biogas system concern current expenses on diesel for electricity production; electricity production for closed stables (valued at grid prices); and, in the case of the full power scenario (see Table 73), electricity sales to the local REE.

Table 73: Revenue BVB Investment Corp farm biogas system (full production)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement	Litres	57,971	0.50	28,985
Future additional electricity demand	kWh	211,992	0.15	31,799
Grid supply	kWh	658,564	0.10	65,856
Total revenue	**US$**			**126,640**

As shown in Table 73, revenues from grid supply account for 65,856 US$/a which is more than half of the total. In the captive power scenario this source of revenue is not included, leading to a decrease of 52%.

Table 74: Revenue BVB Investment Corp farm biogas system (captive power)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement	Litres	57,971	0.50	28,985
Future additional electricity demand	kWh	211,992	0.15	31,799
Total revenue	**US$**			**60,784**

10.7.5 Cash flow analysis

Table 75 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years) in the ***full production*** scenario. The annual net cash flow is positive over the complete project period.

Table 75: Cash flow BVB Investment Corp farm biogas system (full production)

Item / Year	0	1	2	3	4	5	6
Equity	62,000	0	0	0	0	0	0
Debt financing	143,000	0	0	0	0	0	0
Short term financing	0	976	0	0	0	0	0
Inflow from operations	0	126,640	126,640	126,640	126,640	126,640	126,640
Total inflow	**205,000**	**127,616**	**126,640**	**126,640**	**126,640**	**126,640**	**126,640**
Increase fixed assets	198,000	0	0	0	0	61,600	0
Increase current assets	0	10,976	0	0	0	0	0
Operating costs	0	11,710	11,710	11,710	11,710	11,710	11,710
Corporate tax	0	16,014	16,543	17,072	17,601	18,130	18,659
Interest payable	6,614	13,228	10,582	7,937	5,291	2,646	0
Loan repayments	0	28,600	28,600	28,600	28,600	28,600	0
Total outflow	**204,614**	**80,527**	**67,435**	**65,319**	**63,202**	**122,686**	**30,369**
Net cash flow	**386**	**47,089**	**59,205**	**61,322**	**63,438**	**3,955**	**96,271**
Cumulative	**386**	**47,475**	**106,680**	**168,002**	**231,441**	**235,395**	**331,666**

Table 76 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years) in the ***captive power*** scenario. There are negative net cash flows in years 5 and 10, because of reinvestments, but the cumulative net cashflow is positive over the complete project period.

Table 76: Cash flow BVB Investment Corp farm biogas system (captive power)

Item / Year	0	1	2	3	4	5	6
Equity	37,000	0	0	0	0	0	0
Debt financing	87,000	0	0	0	0	0	0
Short term financing	0	819	0	0	0	0	0
Inflow from operations	0	60,784	60,784	60,784	60,784	60,784	60,784
Total inflow	**124,000**	**61,603**	**60,784**	**60,784**	**60,784**	**60,784**	**60,784**
Increase fixed assets	114,400	0	0	0	0	56,100	0
Increase current assets	0	0	0	0	0	0	0
Operating costs	0	9,830	9,830	9,830	9,830	9,830	9,830
Corporate tax	0	5,531	5,853	6,174	6,496	6,818	7,140
Interest payable	4,024	8,048	6,438	4,829	3,219	1,610	0
Loan repayments	0	17,400	17,400	17,400	17,400	17,400	0
Total outflow	**118,424**	**40,808**	**39,521**	**38,233**	**36,945**	**91,758**	**16,970**
Net cash flow	**5,576**	**20,795**	**21,264**	**22,551**	**23,839**	**-30,974**	**43,814**
Cumulative	**5,576**	**26,371**	**47,635**	**70,186**	**94,025**	**63,051**	**106,865**

Table 77 shows financial indicators calculated from the cash flows for both scenarios. For the ***full production*** scenario, the Levelised Cost of Electricity (LCOE) of 0.058 US$/kWh, which is well below the expected feed-in rate for electricity and far below the price of diesel-generated electricity (>0.25 US$/kWh). Simple Payback Period is approx. 1.8 years.

In the ***captive power*** scenario, LCOE is 0.118 US$/kWh which considerably higher than in the full production scenario, but still well below the tariff for grid electricity (0.15 US$/kWh) and the cost of diesel-generated electricity. Simple Payback Period is 2.3 years.

Table 77: Indicators BVB Investment Corp farm biogas system

Item	Unit	Full production	Captive power
LCOE	US$/kWh	0.058	0.118
IRR	%	45%	34%
NPV	US$	340,900	112,940
Return on Equity	%	87%	64%
Simple Payback period	years	1.8 years	2.3 years

10.7.6 Sensitivity analysis

The cashflow analyses show the best economic results for the full production scenario; the sensitivity analysis is therefore limited to this scenario only. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.

- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 54 below.

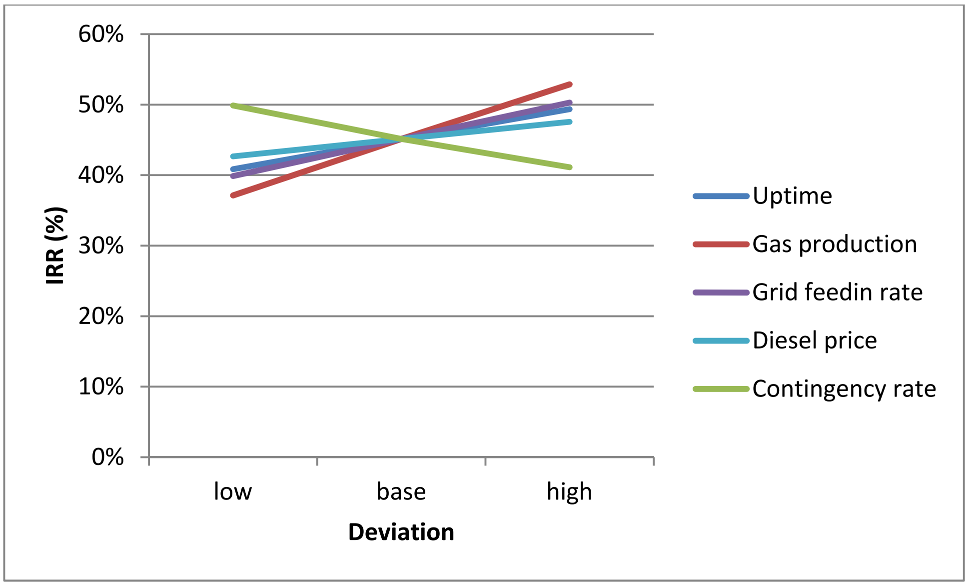

Figure 54: Sensitivity analysis BVB Investment Corp farm biogas project

The results show that variations in diesel price (±20%) have limited effect on the project economics, leading to changes in IRR of just ±2.5% points. Variations in contingency rate (10±10%), generator availability (90±10%) and grid feed-in tariff (±20%) have a somewhat higher effect, leading to IRR variations of ±4-5% points. The project economics are most sensitive to deviations of gas production; variations of ±20% lead to IRR changes of approx. ±8% points.

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%), higher generator availability (100%) and higher investment costs (20% contingency rate) results in an IRR of 51%
- Reduced generator uptime (80%) and lower feed-in rate (-20%) result in an IRR of 36%
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of 25%.
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 74%.

Other factors of influence:

- The development of additional on-farm electricity consumption (closing the stables) has a pronounced positive effect but is not critical. If this demand is ***not*** included, IRR will drop to 38%.
- Selecting a low-cost solution for the generator will increase the IRR to 52%. A 25% reduction in water consumption increases IRR to 49%.

10.7.7 Success factors

A comparison of this project with others in the sector shows that the good economics of this project can be explained with the following combination of factors:

- Economies of scale, leading to lower investment costs per production unit.
- A larger generator which has a higher electrical efficiency, leading to a relatively high electricity production.
- Low water use, resulting in a relatively high DM content of the slurry and thus a more cost efficient digester.
- High own demand, leading to a higher valuation of the energy produced.

10.8 Conclusions

The average biogas production potential at BVB Investment Corp farm is approx. 1,592 m^3/d, with fluctuations of ±25%. Both a full production scenario and a captive power scenario have been assessed:

- The full production scenario features a covered lagoon digester with a volume of 14,200 m^3 and a 240 kW (300 kVA) gas generator. Electricity production potential is approx. 3,026 kWh/d on average (993,896 kWh/a) which can either be used on the farm or fed into the local REE distribution grid.
- In the captive power scenario, digester volume of 4,700 m^3 and 200 kW (250 kVA) gas generator suffice. Electricity production would be approx. 335,333 kWh/a.

Total investment costs of the ***full production*** system is 204,614 US$; for the ***captive power*** system it is 118,424 US$. However, the full production scenario has much higher revenues, resulting in better economics (IRR of 45%, Simple Payback period of 1.8 years). In the captive power scenario, the project IRR is 34% and its simple payback period is 2.3 years.

In the full production scenario, the project economics are equally sensitive to deviations in generator availability, biogas production rate and investment costs; if all three variables deviate to the negative side, IRR drops to 7%. Project IRR is not sensitive to diesel price.

11 FEASIBILITY STUDY: NEANG CHANTHA

Table 78: Neang Chantha farm location and contact

Farm	Neang Chantha
Village	Samaky
Commune	Chrok Mtes
District	Krong Bavet
Province	Svay Rieng
GPS	11.0422N, 105.9801E
Owner	Mr. Neang Chantha 089 818 241

11.1 Introduction

The pig farm of Neang Chantha is located in Svay Rieng province in the east of Cambodia, some 15 km east of Krong Svay Rieng. It is a mixed farm, featuring both pig breeding and pig fattening; the average number of animals is approx. 2,200 heads. The numbers of animals and the variation therein are shown in Table 79 below.

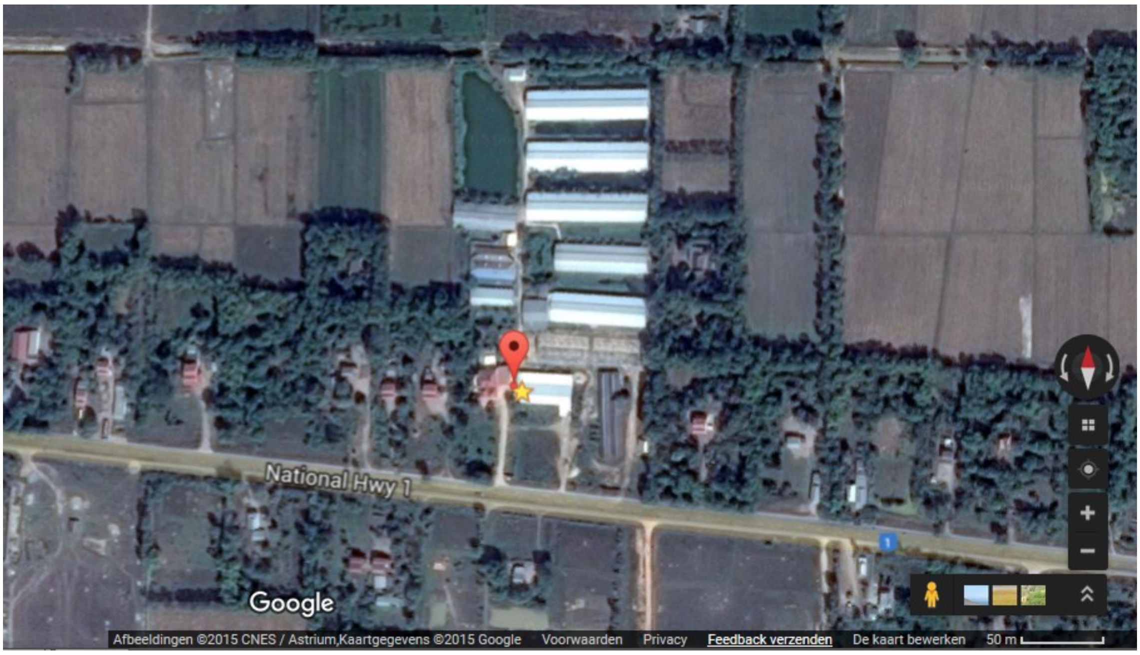

Figure 55: Map of Neang Chantha pig farm

The farm has a total of 9 stables: 4 for fattening pigs, 3 for sows, 1 for weaners and 1 for boar. There is also a rice mill and feed milling and mixing equipment on the farm. Just north of the farm, the owner also has 5ha of rice land and 9ha of land under eucalyptus.

There is some experience with biogas on the farm: a 15 m^3 fixed dome system is in use, producing gas for cooking from solid dung and water.

11.2 Farm operation

The farm breeds its own pigs for fattening: production of piglets is about 500 heads per month, which are weaned in the nursery for about a month to a weight of around 17-18kg per head. About 15-20% is then sold and the rest is fattened on the farm, for a period of approx. 3 months until they reach a weight of approx. 90kg.

Pig feed is prepared on the farm, from rice, maize and protein. Total feed consumption of the farm is approx. 85-90t/m. Fattening pigs get free intake (approx. 1.4 kg/head/d, excluding weaners), suckling sows are fed 5-6kg/head/d, pregnant sows 2.5-3kg/head/d.

The stables of the fattening pigs each have 32 pens, holding 20 animals each. The far side of each pen is a bath that is connected to the baths of all other pens in that row. The baths (4.5x0.8x0.1m = 0.36 m^3) are always filled with water, which is changed every day after the solid manure in the pen has been pushed in the bath and the pens are hosed down.

The other stables are cleaned on a daily basis as well. The solid dung from one of the sow stables is collected every day for feeding the biogas system.

11.3 Biogas feedstock

11.3.1 Manure and urine production

Table 79 gives an overview of the production of dung, urine and dry matter therein. The pig slurry from all stables is channelled into a pond (approx. 10x30m) in the centre of the farm premises. There is no slurry removal; water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

Table 79: Average livestock, dung and urine production at Neang Chantha farm

Animal	Heads	Variation	Fresh dung (t/d)	Urine (m^3/d)	Total DM (t/d)
Fattening pigs	1,800	±10%	1.41	4.5	0.54
Sows	450	±10%	0.70	2.3	0.27
Boar	8	N/A	0.02	0.0	0.01
Total	**2,258**		**2.13**	**6.8**	**0.82**

11.3.2 Water consumption

Water for the Neang Chantha farm is pumped from five boreholes by five electric pumps. On the basis of spot water flow measurements, total water consumption is estimated at 149 m^3 per day:

- Changing of bathing water in fattening stables: 41 m^3/d (10.4 m^3/d per stable in 4 stables, every day)
- Cleaning of pens with hose: 108 m^3/d (72m^3/d for fattening stables, plus 36 m^3/d for other stables)

Note that this water consumption is more than 70% above the average found in the sector, and more than three times the quantity of the sector best. In order to reduce the biogas system volume, and the energy consumption of water pumps, a water consumption reduction would be highly desirable (e.g. by closing off water when not in use, or using pressurized water for hosing). In the view of the performance of other companies, a saving of 30% should be obtainable which is assumed in the further analyses. Water consumption is than at level with the higher consumption levels found at other farms.

Water evaporation is estimated at 0.5 m^3/d/stable or 4 m^3/d in total.

Figure 56: Fattening stable interior

Figure 57: Rice mill at Neang Chantha farm

11.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 80 below.

Table 80: Total waste production at Neang Chantha farm

Source	Unit	average	minimum	maximum
Water	t/d	105	105	105
Dung (fresh)	t/d	2.1	1.9	2.3
Urine	t/d	6.8	6.1	7.5
Evaporation	t/d	4.0	4.0	4.0
Total slurry	t/d	110	109	110
DM content	%	0.7%	0.7%	0.8%

11.3.4 Biogas and electricity production potential

Table 81 below gives an overview of the biogas and electricity production potentials of the different sources of dung, as well as the variation therein. Biogas production is based on 300 m^3/tDM for pig slurry. Electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency). Annual electricity production potential would be 136,776 kWh/a.

Table 81: Biogas and electricity production potential at Neang Chantha farm

Source	Unit	Average	Minimum	Maximum
Total biogas	**m^3/d**	**245**	**221**	**269**
Total electricity	kWh/d	416	375	458
Total electricity (at 90% genset availability)	kWh/a	136,776		

11.4 Energy demand and supply

11.4.1 Energy demand

At present, energy consumption on the farm site consists of the following:

- Feed preparation: corn and broken rice are ground with a 30kW grinder and then mixed with a 7.5kW mixer. The system is used every day for 2-3 hours.
- Water pumping: one drinking water pump (1.1 kW) is run 3 times per day for 2-3 hours, and 4 cleaning water pumps are used when cleaning (3 h/d).
- Stable lighting: in the fattening stables 3x18W and in suckling stable 10-15x18W, used for three h/d in the evening. In the suckling stable, approx. 70x60W incandescent lamps are used (all night), for heating. Total load is 4.7 kW.
- A/C in the owner's house: 3x1.5hp = 3.5kW during night-time.
- Other consumption of owner's house and workers houses.

On the basis of this equipment, average daily consumption is estimated at approx. 140 kWh/d. Electricity is supplied from the grid, which runs right past the farm premises; price is 0.145 US$/kWh. Two backup generators are in place but these are not regularly used. Electricity bills from January to August 2015 show average monthly consumption of the farm of 3,079 kWh/month, with ±15% variation between months. Average daily consumption is thus 103 kWh/day.

Figure 58 below shows the load curve as measured on 18-19 September 2015. It concerns 1-minute averages; startup current of the feed mill was more than 100A (70kVA). Total daily electricity consumption during the measured period was 163 kWh which is significantly above the average; nonetheless, according to the farm manager it was a typical day. On the basis of the equipment, the measurements and the electricity bills, an average daily consumption of 125 kWh/d is used in the further calculations.

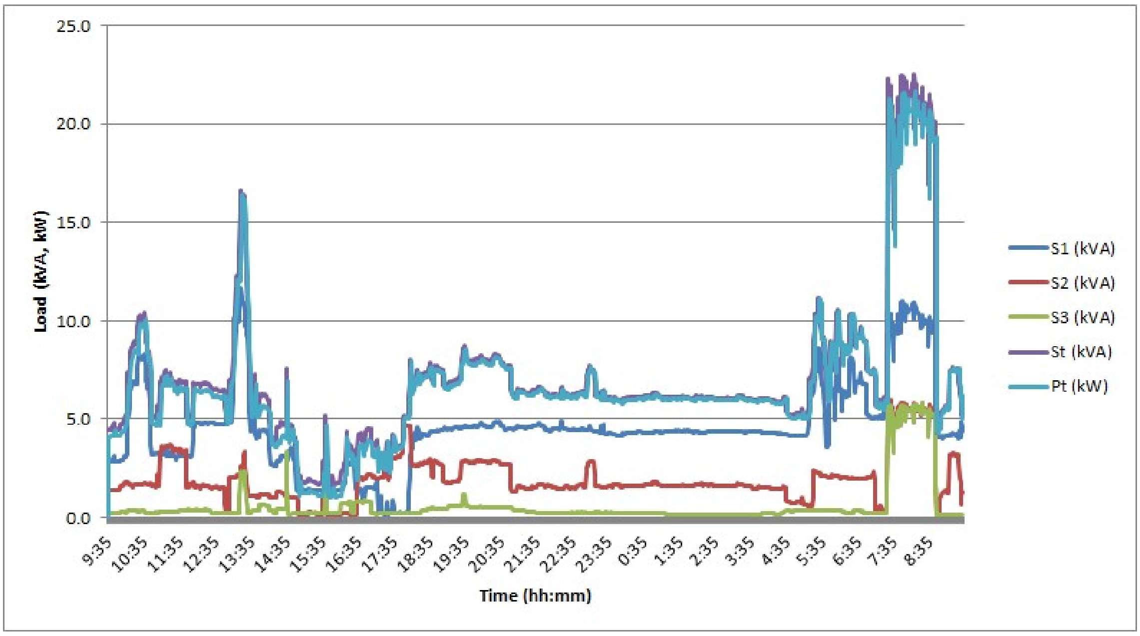

Figure 58: Load curve at Neang Chantha pig farm

In addition to the electrical equipment, there is a diesel driven rice mill at the farm. The mill typically runs once per week for 3-4 hours, producing on average about 600 kg of rice, consuming some 10 litres of diesel. The diesel engine has a capacity of 35 horsepower. When fitted with an electric drive, its consumption would be approx. 25 kWh per week.

Total annual electricity demand would be 46,929 kWh/a. Peak loads would occur when starting up the feed mill (or the rice mill if it would be driven electrically). With soft starting equipment, peak loads could be limited to approx. 40kVA.

11.4.2 Supply strategy

For the use of the biogas, a 40kW (50kVA) gas engine is proposed. It would run for a maximum number of hours (e.g. approx. 16 h/d). It could cover the full load of the farm (including the feed mill and the rice mill, if not run simultaneously) and supply excess power to the grid during daytime and night time.

11.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 38.4 t/a (961 tCO_{2eq} /a)
- Diesel fuel reduction is 468 l/a (1 tCO_{2eq} /a)
- Grid electricity substitution in 88,332 kWh/a (58 tCO_{2eq} /a)[23]
- Total GHG reduction is thus 1,020 tCO_{2eq} /a

11.6 Biogas plant description

11.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (110 m^3/d) and the recommended retention time of 30 days, digester volume is set at 3,300 m^3. Dimensions of the lagoon will be approx. 50x20x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 60x30m. Note that these dimensions are provisional and will be set during final design.

At present, waste water already flows from each stable to a central collection point. At this point, it will enter a sedimentation tank from where it will be pumped into the digester. A circulation pump will be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as done currently.

[23] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as grid demand (by EDC) is only a fraction of the potential

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

11.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 40 kW (50 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid running along the road in front of the farm.

Any excess biogas will be burnt off with a flare.

11.7 Financial analyses

11.7.1 Basic parameters

Table 82 shows the basic parameters used in the financial calculations.

Table 82: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average operator salaries found in the industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas (February 2016).
Electricity price	US$/kWh	0.150	Based on EAC established tariffs post-2015
Feed-in tariff	US$/kWh	0.100	Based on indications from EDC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

11.7.2 Investment costs

Table 83 below gives an overview of the investment costs of the biogas system at Neang Chantha farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 83: Investment costs Neang Chantha farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	24,000	15	2%
Pumps	1,000	5	5%
Structures	9,000	20	2%
Gas treatment	5,000	10	5%
Generator	16,000	5	10%
Electrical systems	8,000	15	2%
Engineering and installation	5,000	15	0%
Sub-total	**68,000**	**N/A**	**N/A**
Contingencies	6,800	N/A	N/A
Pre-production financial costs	2,498	N/A	N/A
Total investment costs	**77,298**	**N/A**	**N/A**

Options for investment costs reductions include the following:

- If water consumption at the farm can be reduced, the size of the digester can be reduced. A 25% water reduction could thus reduce investment costs with some 3,300 US$.
- As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 8,800 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Net working capital is estimated at some 536 US$; this is built up of accounts receivable (788 US$) minus accounts payable (252 US$).

11.7.3 Production costs

Table 84 shows the annual operating and production costs of the biogas system. Note that in the operating costs, maintenance of the generator takes up the largest part (33%), followed by staff costs (30%) and digester maintenance (16%). The remainder is maintenance for other equipment.

Table 84: Production costs Neang Chantha farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	2,120	2,120	2,120	2,120	2,120	2,120
Operating costs	**3,020**	**3,020**	**3,020**	**3,020**	**3,020**	**3,020**
Depreciation	7,498	7,498	7,498	7,498	7,498	7,498
Financing costs	4,995	3,996	2,997	1,998	999	0
Production costs	**15,513**	**14,514**	**13,515**	**12,516**	**11,517**	**10,518**

11.7.4 Revenues

Revenues from the biogas system concern replacement of electricity from the grid; current expenses on diesel for rice milling; and electricity sales to the EDC grid.

Table 85: Revenue Neang Chantha farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Replacement electricity consumption	kWh	41,063	0.15	6,159
Diesel replacement rice milling	litres	468	0.50	234
Grid supply	kWh	47,270	0.10	4,727
Total revenue	**US$**			**11,120**

EDC has indicated to be willing to consider a price level below 0.10 US$/kWh, but that they will only purchase electricity during the dry season (January-May/June). The quantity of electricity sold is therefor set at 50% of the potential (see section 11.3.4).

11.7.5 Cash flow analysis

Table 86 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). There is a negative net cash flow during the loan repayment period, but from year 6 onwards it is positive with the exception of year 10 (because of required re-investments). The cumulative net cash flow becomes positive after year 13.

Table 86: Cash flow Neang Chantha farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	24,000	0	0	0	0	0	0
Debt financing	54,000	0	0	0	0	0	0
Short term financing	0	252	0	0	0	0	0
Inflow from operations	0	11,120	11,120	11,120	11,120	11,120	11,120
Total inflow	**78,000**	**11,372**	**11,120**	**11,120**	**11,120**	**11,120**	**11,120**
Increase fixed assets	74,800	0	0	0	0	18,700	0
Increase current assets	0	788	0	0	0	0	0
Operating costs	0	3,020	3,020	3,020	3,020	3,020	3,020
Corporate tax	0	0	0	0	0	0	120
Interest payable	2,498	4,995	3,996	2,997	1,998	999	0
Loan repayments	0	10,800	10,800	10,800	10,800	10,800	0
Total outflow	**77,298**	**19,603**	**17,816**	**16,817**	**15,818**	**33,519**	**3,140**
Net cash flow	**703**	**-8,231**	**-6,696**	**-5,697**	**-4,698**	**-22,399**	**7,980**
Cumulative	**703**	**-7,528**	**-14,224**	**-19,921**	**-24,618**	**-47,017**	**-39,037**

Table 87 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.223 US$/kWh, which is well above the grid prices for consumption and feed-in.

Table 87: Indicators Neang Chantha farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.223
IRR	%	1%
NPV	US$	-41,375
Simple Payback period	years	9.5 years

11.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l; in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 59 below.

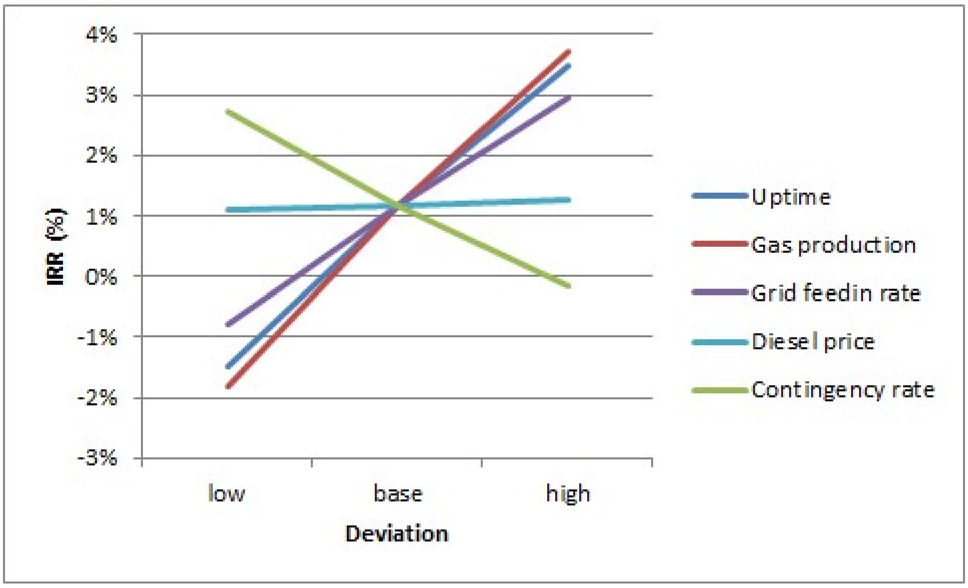

Figure 59: Sensitivity analysis Neang Chantha farm biogas project

The results show that project economics are practically insensitive to variations in the diesel price. Changes in investment costs (contingency rate 10±10%) results in IRR changes of approx. 1.5% points; for both grid feed-in tariff (±20%) and generator availability (90±10%) this is approx. ±2.5% points. The project economics are most sensitive to deviations of gas production; variations of ±20% lead to IRR changes of ±3% points.

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20), higher generator uptime (100%) and higher investment costs (20% contingency rate) results in an IRR of 5%.
- Reduced generator uptime (80%) and lower feed-in rate (-20%) result in an IRR of -1%.

- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of -8% (simple payback period of 16.8 years).
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 10% (payback period of 5.7 years).

The level of electricity demand has a higher effect on project economics. If electricity could be sold to the grid throughout the year, IRR would increase to 8%. If on-farm electricity demand would increase to 54,750 kWh/a (6 closed stables), IRR would increase to 10%. A combination of both would result in an IRR of 12%.

Selecting a low-cost solution for the generator will increase the IRR to 3%. A 25% reduction in water consumption increases IRR to 2%.

11.8 Conclusions

The average biogas production potential at Neang Chantha farm is approx. 245 m^3/d, with fluctuations of ±10%. Electricity production potential is approx. 416 kWh/d on average (136,776 kWh/a). Water consumption is very high and would need to be reduced in order to arrive at normal levels found in the sector. The project features a covered lagoon digester with a volume of 3,300 m^3 and a 32kW (40 kVA) gas generator. About 31% of the electricity can be used on-site, replacing energy that is now consumed from the grid; part of the remainder can be supplied to the EDC grid.

Total investment costs in the system are 77,298 US$. In the base case scenario, the Levelised Cost of Electricity is 0.201 which is well above the grid feed-in rate and the electricity purchase price. The financial outlook of the project can be significantly improved increasing the demand for electricity, from the grid or for the farm itself.

12 FEASIBILITY STUDY: CHHIN SONG

Table 88: Chhin Song farm location and contact

Farm	Chhin Song
Village	Pou Tbaeng
Commune	Nitean
District	Bor Seth
Province	Kampong Speu
GPS	11.1279N, 104.6145E
Owner	Mr. Chhin Song 012 342 442

12.1 Introduction

The farm of Mr. Chhin Song is located in Kampong Speu province, some 60km Southwest of Phnom Penh. The farm is a fattening farm, working under contract for C.P. Cambodia. The farm has a total of 8 stables with a holding capacity of 600 heads each, i.e. a total capacity of 4,800 heads. It was constructed recently; during the company visit (February 2016) the last two stables were being finalised.

Figure 60: Approximate layout of Chhin Song farm

12.2 Farm operation

Under the contract agreement with the C.P. Company, C.P. provides piglets, feed and pharmaceuticals. The farm then raises the pigs during a period of some 5 months from approx. 5kg to 100kg each, following C.P. instructions. C.P collects the finished pigs and pays the farm per kg of animal weight. Within a month, new piglets are brought for the next cycle.

Note that C.P. practices an “all in, all out” system. At the end of each cycle, all the finished pigs are collected, completely emptying all the stables. The stables remain empty for 2-4 weeks, allowing the farm to clean and disinfect the stables. Subsequently, the new cycle starts with filling the stables with new piglets. This is standard C.P. procedure, reducing the movements to and from each farm to a minimum in order to minimize the risk of spreading disease.

The farm has closed stables only. Each stable has a series of draught fans in the back; depending on the temperature inside the stable, one or more fans are automatically switched on or off. There is a water curtain in the front of the stable for cooling down the incoming air.

Figure 61: Chhin Song farm

Figure 62: Fans in the back of a closed stable

12.3 Biogas feedstock

12.3.1 Manure and urine production

Average daily dung production is estimated at 3.8 tonnes per day. There is a large variation in dung availability, as four times per year half the animals in the farm are replaced with piglets whose dung production is initially very low. During the growth of the pigs, this increases gradually to a level of some 1.25 kg/head/day (based on a max feed intake of 2.5 kg/head/day). Fresh dung production will thus vary between 0 and approx. 7.5 t/d. Total dry matter production (including solids from urine) will be approx. 1.4 t/d, varying between 0 and 2.9 t/d.

Urine production will also vary throughout the cycle, but is on average 12 m^3/d.

The dung, urine and cleaning water from the stables flow through underground piping into one of four ponds (three of 30x50x5.5m and one of 30x60x5.5m) located behind the stables. There is no further use of the slurry.

12.3.2 Water consumption

Water for the Chhin Song farm is pumped from three borehole on the farm site. Apart from drinking water, water consumption at the farm is estimated at approx. 179 m^3/d (based on spot water flow measurements). It consists of the following components:

- Cleaning of the pens. This is done every day, using high pressure spray water, taking approx. 2 hours per stable and which consumes 2.9 m^3 of water for each stable. Total average water consumption for the four stables is approx. 23 m^3/d.
- Refreshing the bath water. This is done every day after cleaning. Daily water consumption for the eight stables is approx. 156 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 4 m^3/d.

12.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 89 below.

Table 89: Total waste production at Chhin Song farm

Source	Unit	average	minimum	maximum
Water	t/d	179	179	179
Dung (fresh)	t/d	3.8	0.0	7.5
Urine	t/d	12	0	24
Evaporation	t/d	4.0	4.0	4.0
Total waste water	t/d	190	175	206
DM content	%	0.8%	0%	1.4%

Waste production (40 l/head/day) is just below the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d). This is mainly due to the high water consumption by bath water refreshing.

12.3.4 Biogas and electricity production potential

Table 90 below gives an overview of the biogas and electricity production potential at Chren Vorn farm, and variation therein. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency, due to small size). Annual electricity production potential on the basis of biogas availability would be 258,056 kWh/a; assuming 90% generator set availability, total annual electricity production would be 241,250 kWh/a.

Table 90: Biogas and electricity production potential at Chhin Song farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	432	0	864
Total electricity	kWh/d	734	0	1,469
Total electricity (at 90% genset availability)	kWh/a	241,250		

12.4 Energy demand and supply

12.4.1 Energy demand

Energy consumption at the Chhin Song farm concerns the following:

- There are three borehole pumps of 0.37 kW each, and two booster pumps of 2.3 kW each that pump the water into an elevated storage. Total electricity consumption is estimated at approx. 25 kWh/d.
- There are 4 spray water pressurisation pumps of 1.5 kW each, which are used during cleaning. Daily consumption is approx. 21 kWh/d.
- Each stable has six fans (four of 0.75 kW, two of 0.37 kW) and a water pump (0.5 kW). Daily consumption of each barn is estimated at 25 kWh/d.

- Each stable has 30 pcs of 60W incandescent lamps used for keeping the young piglets warm at night during their first month. Electricity consumption during two months per year is 173 kWh/d.

Total annual electricity demand is estimated at 85,122 kWh. Because of the incandescent lamps, and the short periods with empty stables, monthly demand will fluctuate. Peak demand will be below 40 kVA.

Note that the farm owner also has a license for the supply of electricity in his region. He purchases electricity from EDC (600,000 kWh/month), and supplies it to his customers (and his farm) through his MV and LV grid system. The load in his system varies between 0.5 and 1 MW. All things considered, Mr. Chhin Song can distribute all the electricity he can produce from biogas, regardless of the consumption at the farm, the season, or the time of day.

12.4.2 Supply strategy

The electricity demand at the Chhin Song farm amounts to approx. 32% of the total electricity production potential. Two production scenarios can be distinguished: i) production of captive power only, and ii) full utilisation of the biogas potential, supplying excess electricity to the grid.

Captive power

In the case of captive power production, the biogas is used for meeting the on-farm electricity demand only. A somewhat smaller digester is required as biogas demand is limited. As the peak load is estimated at 40 kVA, a genset of 50 kVA is proposed. During periods of low gas availability, part of the electricity will need to be supplied by the grid; the generator will then only run for a limited number of hours. During periods of high gas production, excess gas will need to be flared.

Full production

In the case of full production, all biogas is converted to electricity, and the electricity not used on-farm is fed into the grid. There is no practical limitation to this, and the varying availability of biogas is no problem as EDC can supply more electricity in times of low availability.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (864 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 100 kW (125 kVA) genset. In periods of high biogas availability, the generator can run for approx. 16 h/d; in periods of low gas availability it can run for fewer hours per day or not at all.

12.5 GHG emission reductions

Greenhouse gas reductions from this project for the full production scenario are established as follows:

- Methane emission reduction is 82 t/a (2,042 tCO_{2eq} /a).
- Grid electricity substitution is 241,250 kWh/a (158 tCO_{2eq}/a).
- Total GHG reduction is thus 2,200 tCO_{2eq} /a.

For the captive power scenario is as follows:

- Methane emission reduction is 47 t/a (1,174 tCO_{2eq} /a).
- Grid electricity substitution is 76,610 kWh/a (50 tCO_{2eq}/a).
- Total GHG reduction is thus 1,224 tCO_{2eq} /a.

12.6 Biogas plant description

12.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

In the ***full production scenario***, the maximum daily amount of waste water (206 m^3/d) and the recommended retention time of 30 days result in a digester volume of 6,200 m^3. In the ***captive power*** scenario, the maximum daily electricity demand that must be met is 422 kWh/d, requiring 248 m^3/d of biogas resulting in a digester of 3,300 m^3 volume. In principle, one of the existing lagoons could be used for this; the smaller lagoons (50x30x5.5m) have a volume of 6,000 m^3 and the larger lagoon (60x30x5.5m) has a volume of 7,400 m^3.

The existing wastewater removal system is already directly usable for linking the stables to the system. A sedimentation tank would be installed, from where the waste it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be evacuated to surrounding fields or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

12.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 40 kW (50 kVA) or 100 kW (125 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

In the ***full power scenario***, grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid.

Any excess biogas will be burnt off with a flare.

12.7 Financial analyses

12.7.1 Basic parameters

Table 91 shows the basic parameters used in the financial calculations.

Table 91: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	2,400	Indicated by farm owner
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas
Feed-in tariff	US$/kWh	0.126	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

12.7.2 Investment costs

Table 92 below gives an overview of the investment costs of the biogas system at Chhin Song farm in the ***full production*** scenario. The digester costs are based on indications from existing biogas plants, with a reduction because the excavation work has already been done. Other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 92: Investment costs Chhin Song farm biogas system (full production)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	32,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	6,000	10	5%
Generator	32,000	5	10%
Electrical systems	11,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**92,000**	**N/A**	**N/A**
Contingencies	9,200	N/A	N/A
Pre-production financial costs	3,376	N/A	N/A
Total investment costs	**104,576**	**N/A**	**N/A**

As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 16,000 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Table 93 gives an overview of investment costs in the ***captive power*** scenario.

Table 93: Investment costs Chhin Song farm biogas system (captive power)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	21,000	15	2%
Pumps	1,000	5	5%
Structures	5,000	20	2%
Gas treatment	5,000	10	5%
Generator	19,000	5	10%
Electrical systems	0	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**56,000**	**N/A**	**N/A**
Contingencies	5,600	N/A	N/A
Pre-production financial costs	2,081	N/A	N/A
Total investment costs	**63,681**	**N/A**	**N/A**

Choosing a modified diesel engine would result in a cost reduction of some 10,000 USD, here also with a reduced life span.

In both cases, Net working capital would be negative: the electricity that is produced replaces part of what the owner currently purchases from EDC, i.e. there is no accounts receivable. Accounts payable – one month of all operating costs – amounts to 476 US$ in the full production scenario, and 327 US$ in the captive power scenario.

12.7.3 Production costs

Table 94 shows the operating and production costs of the biogas system in the first 6 years, in the ***full production*** scenario. Note that in the operating costs, maintenance of the generator takes up the largest part (56%), followed by staff costs (21%) and digester maintenance (11%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 12.7.1), these will remain 0 from year 6 onwards.

Table 94: Production costs Chhin Song farm biogas system (full production)

Item / Year	1	2	3	4	5	6
Staff	1,200	1,200	1,200	1,200	1,200	1,200
Maintenance	4,510	4,510	4,510	4,510	4,510	4,510
Operating costs	**5,710**	**5,710**	**5,710**	**5,710**	**5,710**	**5,710**
Depreciation	11,715	11,715	11,715	11,715	11,715	11,715
Financing costs	6,753	5,402	4,052	2,701	1,351	0
Production costs	**24,178**	**22,827**	**21,477**	**20,126**	**18,776**	**17,425**

Table 95: Production costs Chhin Song farm biogas system (captive power)

Item / Year	1	2	3	4	5	6
Staff	1,200	1,200	1,200	1,200	1,200	1,200
Maintenance	2,720	2,720	2,720	2,720	2,720	2,720
Operating costs	**3,920**	**3,920**	**3,920**	**3,920**	**3,920**	**3,920**
Depreciation	7,132	7,132	7,132	7,132	7,132	7,132
Financing costs	4,163	3,330	2,498	1,665	833	0
Production costs	**15,214**	**14,382**	**13,549**	**12,717**	**11,884**	**11,052**

Table 95 shows production costs in the ***captive power*** scenario. Annual production costs are approx. 37% lower than in the full production scenario. Generator maintenance remains the largest cost item (48%) followed by staff costs (31%).

12.7.4 Revenues

In both scenarios, all electricity can be considered as used by the owner himself, either for satisfying on-farm demand or for distribution to his customers. The electricity is valued at the price for alternative electricity supply, which is purchase from EDC at 0.126 US$/kWh. The resulting annual revenue in the full production scenario shown in Table 96.

Table 96: Revenue Chhin Song farm biogas system (full production)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Grid sales	kWh	241,250	0.126	30,398
Total revenue	**US$**			**30,398**

In case of ***captive power*** scenario, the annual electricity production is 76610 kWh and the annual revenue is 9,653 US$/a. This is 68% lower than in the full production scenario.

12.7.5 Cash flow analysis

Table 97 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years), in the full production scenario. There is a negative cash flow in year 5 that would require short term financing.

Table 97: Cash flow Chhin Song farm biogas system (full production)

Item / Year	0	1	2	3	4	5	6
Equity	32,000	0	0	0	0	0	0
Debt financing	73,000	0	0	0	0	0	0
Short term financing	0	476	0	0	0	0	0
Inflow from operations	0	30,398	30,398	30,398	30,398	30,398	30,398
Total inflow	**105,000**	**30,873**	**30,398**	**30,398**	**30,398**	**30,398**	**30,398**
Increase fixed assets	101,200	0	0	0	0	36,300	0
Increase current assets	0	0	0	0	0	0	0
Operating costs	0	5,710	5,710	5,710	5,710	5,710	5,710
Corporate tax	0	1,244	1,514	1,784	2,054	2,324	2,595
Interest payable	3,376	6,753	5,402	4,052	2,701	1,351	0
Loan repayments	0	14,600	14,600	14,600	14,600	14,600	0
Total outflow	**104,576**	**28,307**	**27,226**	**26,146**	**25,065**	**60,285**	**8,305**
Net cash flow	**424**	**2,567**	**3,171**	**4,252**	**5,332**	**-29,887**	**22,093**
Cumulative	**424**	**2,991**	**6,162**	**10,414**	**15,746**	**-14,141**	**7,952**

Table 98 below shows the cash flows in the captive power scenario. In this scenario, net cashflows are negative throughout the loan repayment period, from year 6 onwards they are positive except for a negative cashflow in year 10 because of reinvestment. Throughout the project period, the cumulative cash flow remains negative.

Table 98: Cash flow Chhin Song farm biogas system (captive power)

Item / Year	0	1	2	3	4	5	6
Equity	19,000	0	0	0	0	0	0
Debt financing	45,000	0	0	0	0	0	0
Short term financing	0	327	0	0	0	0	0
Inflow from operations	0	9,653	9,653	9,653	9,653	9,653	9,653
Total inflow	**63,681**	**17,083**	**16,250**	**15,418**	**14,585**	**35,753**	**3,920**
Increase fixed assets	61,600	0	0	0	0	22,000	0
Increase current assets	0	0	0	0	0	0	0
Operating costs	0	3,920	3,920	3,920	3,920	3,920	3,920
Corporate tax	0	0	0	0	0	0	0
Interest payable	2,081	4,163	3,330	2,498	1,665	833	0
Loan repayments	0	9,000	9,000	9,000	9,000	9,000	0
Total outflow	**63,681**	**17,083**	**16,250**	**15,418**	**14,585**	**35,753**	**3,920**
Net cash flow	**319**	**-7,103**	**-6,597**	**-5,765**	**-4,932**	**-26,100**	**5,733**
Cumulative	**319**	**-6,784**	**-13,381**	**-19,146**	**-24,078**	**-50,178**	**-44,445**

Table 99 shows financial indicators calculated from the cash flows, for both scenarios. For the ***full production*** scenario, the Levelised Cost of Electricity (LCOE) of 0.122 US$/kWh, which is below the electricity price of 0.126 US$/kWh that is now paid to EDC for bulk electricity purchases. Simple Payback Period is approx. 4 years.

In the captive power scenario, LCOE is 0.241 US$/kWh which is nearly twice the electricity price. Simple Payback Period is 10.7 years.

Table 99: Indicators Chhin Song farm biogas system

Item	Unit	Full production	Captive power
LCOE	US$/kWh	0.122	0.241
IRR	%	16%	-4%
NPV	US$	8,031	-44,479
Return on Equity	%	18%	-8%
Simple Payback Period	years	4.1	10.7

12.7.6 Sensitivity analysis

The cashflow analyses show poor economic results for the captive power option; the sensitivity analysis is therefore limited to the full production scenario only. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Diesel price. In the base case this is 0.50 US$/l, in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 63 below.

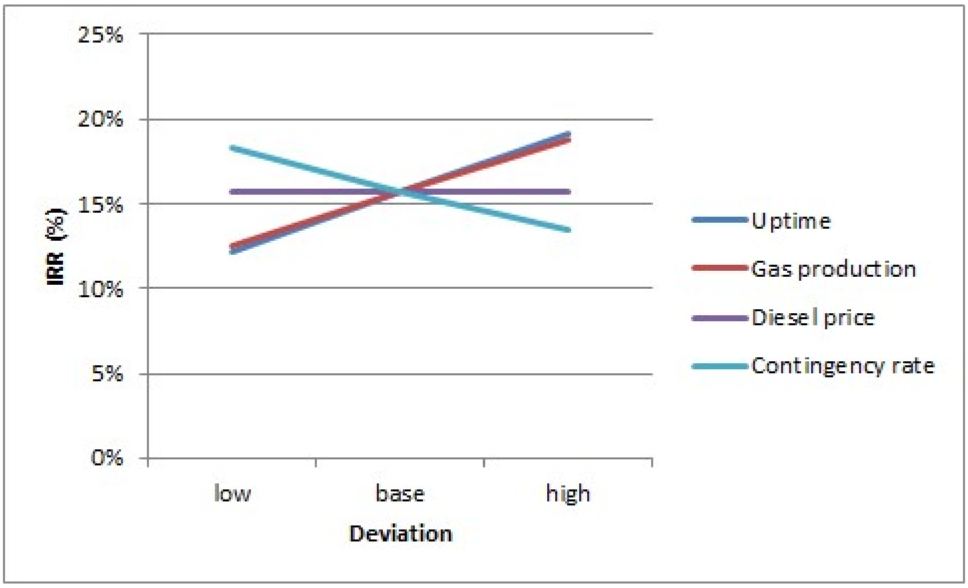

Figure 63: Sensitivity analysis Chhin Song biogas project

The results show that variations in generator availability (90±10%), gas production (±20%) and investment costs (contingency rate 10±10%) all have similar consequences: all result in IRR changes of around 3% points. This means that in all cases, a deviation to the negative side results in the IRR dropping below the discount rate, i.e. NPV dropping below zero. However, the project is not sensitive to diesel price variations as there is no diesel consumption replacement.

Combinations of deviations could result in the following:

- Deviations of different variables to the positive and the negative more-or less result in zero change to IRR. For example, a high generator availability (100%) and a high contingency rate (20%) result in an IRR of 17%, and a low gas production (-10%) and a low contingency rate result in an IRR of 15%.
- A combination of three negative variables to the negative results in an IRR of 7%; a combination of three positive variables results in an IRR of 25%.

In case a reduced water consumption for the cleaning of stables and the changing of baths could be achieved, a smaller digester could be used which would reduce investment costs and slightly increase project IRR. A 25% reduction in water consumption would reduce investment costs with approx. 5,000 US$ and lead to an IRR of 17%.

12.8 Conclusions

The average biogas production potential at Chhin Song farm is approx. 432 m^3/d, with fluctuations of ±100% because of the all-in, all-out system applied. Both a full production scenario and a captive power scenario have been assessed:

- The full production scenario features a covered lagoon digester with a volume of 6,200 m^3 and a 100 kW (125 kVA) gas generator. Electricity production potential is approx. 734 kWh/d on average (241,250 kWh/a) which can either be used on the farm or distributed to consumers in the area under the farm owner's electricity distribution license.
- In the captive power scenario, digester volume of 3,300 m^3 and 40 kW (50 kVA) gas generator suffice. Electricity production would be approx. 76,610 kWh/a.

Total investment costs of the full production system is 104,576 US$; for the captive power system it is 63,681 US$. However, the captive power scenario has much lower revenue, resulting in poor project economics (IRR of -4%, Simple Payback period of 10.7 years). In the full production scenario, the project IRR is 16% and its simple payback period is 4.1 years. The Levelised Cost of Electricity is 0.122 which is just below the price that the farm owner pays for electricity bought in bulk from EDC. It is equally sensitive to deviations in generator availability, biogas production rate and investment costs; if all three variables deviate to the negative side, IRR drops to 7%. Project IRR is not sensitive to diesel price.

13 FEASIBILITY STUDY: KHUN ANG FARM

Table 100: Khun Ang farm location and contact

Farm	Khun Ang
Village	Mean Rith
Commune	Kandoal
District	Teuk Chhou
Province	Kampot
GPS	10.6538N, 104.2823E
Owner	Mr. Khun Ang 012 539 001; 069 539 001

13.1 Introduction

The farm of Mr. Khun Ang is located in Kampot province, some 12km West of the provincial capital Krong Kampot. The owner started the farm in 2010, and gradually expanded it to its current size: 3,400 fattening pigs and 350 sows in 7 stables. The last stable was just constructed and was taken into operation some 2 months earlier.

Figure 64: Approximate layout of Khun Ang farm

13.2 Farm operation

The farm breeds its own pigs for fattening: production of piglets is about 600 heads per month, which are weaned in the nursery for about a month to a weight of around 30kg per head. Most of them are fattened on the farm; only 20-30 are sold each month. The pigs are fattened until they reach an average weight of approx. 100kg.

Piglets and weaners are fed with prepared feed from CP; the feed for all other animals is prepared on the farm, from maize meal, broken rice, soy bean meal, fish meal and some supplements. Feed consumption for fattening pigs is approx. 240kg/head during the whole fattening cycle.

There are 5 stables for fattening pigs, one of which is for holding small pigs (no baths). Hosing is done every day, bath water is changed every other day. The sows, piglets and weaners are kept in two other stables, which are hosed down every day after solid dung has been removed. Part of this dung is used in a small digester (20 m^3) that produces cooking gas, part is used for fertilizing fruit trees (mango, banana) growing between the stables

There are 25-30 workers at the farm, with an average wage of 150 $/month.

13.3 Biogas feedstock

13.3.1 Manure and urine production

Table 101 below gives an overview of the total number of animals, the production of dung and urine and the total amount of solids therein.

Table 101: Average livestock, dung and urine production at Khun Ang farm

Animal	Heads	Variation	Fresh dung (t/d)	Urine (m^3/d)	Total DM (t/d)
Fattening pigs	3,400	N/A	2.66	8.5	1.02
Sows	450	N/A	0.70	0.2	0.23
Boar	6	N/A	0.01	0.0	0.00
Total	**3,856**		**3.37**	**8.7**	**1.25**

Dung, urine and cleaning water from three of the fattening pig stables flow into an intermediate pond (25x40m), and from there to a second pond (30x30m) in the far south of the terrain. The waste water from the two other fattening stables flows there directly. All the waste water flows through open canals. The washing water from the sow and piglet stables, which does not contain much solids, flow directly into adjacent fields.

Figure 65: One of the stables at Khun Ang farm

Figure 66: Feed mill at Khun Ang farm

13.3.2 Water consumption

Water for drinking and washing is pumped from several ponds into reservoirs (drinking water) or directly to the stables (cleaning). There are in total 5 diesel powered pumps. There is also an 80m borehole but it only gives water during the rainy season; water supply is a problem in the hills.

Most of the cleaning water is used in the fattening stables:

- Cleaning of the pens. This is done every day, using high pressure spray water, taking approx. 2 hours per stable and which consumes 5 m^3/d of water for each stable. Total average water consumption for the five stables is approx. 25 m^3/d.
- Refreshing the bath water. This is done every other day after cleaning. Daily water consumption for the four stables with baths stables is approx. 38 m^3/d.

Hosing of the sow stables is done every day, consuming approx. 5 m^3/d for each stable. Total cleaning water consumption on the farm is thus some 72 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 3.5 m^3/d.

13.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 102 below. Waste production (21 l/head/day) is by far the lowest found in the sector.

Table 102: Total waste production at Khun Ang farm

Source	Unit	average	minimum
Water	t/d	73	63
Dung (fresh)	t/d	3.4	3.3
Urine	t/d	9.0	9.0
Evaporation	t/d	3.5	3.5
Total waste water	t/d	82	72
DM content	%	1.5%	1.7%

There is little variation in the production of waste water. However, the total quantity can be reduced by not using the washing water from the two sow stables, and mixing the solid dung that is removed from there with the waste water from the fattening stables. Assuming a 90% recovery of solids, the resulting total waste water volume is 72 m^3 with a solids content of 1.7%.

13.3.4 Biogas and electricity production potential

Table 103 below gives an overview of the biogas and electricity production potential at Khun Ang farm, using the full waste water flow from the fattening stables and the 90% of the solids from the sow stables. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency, due to small size). Annual electricity production potential on the basis of biogas availability would be 229,036 kWh/a; assuming 90% generator set availability, total annual electricity production would be 206,132 kWh/a.

Table 103: Biogas and electricity production potential at Khun Ang farm

	Unit	Average
Total biogas	m^3/d	369
Total electricity	kWh/d	627
Total electricity (at 90% genset availability)	kWh/a	206,132

13.4 Energy demand and supply

13.4.1 Energy demand

Energy consumption at Khun Ang farm concerns the following:

- The five water pumps supplying drinking and cleaning water consume approx. 5 l/d each, i.e. 25 l/d in total (9,125 l/a). The electricity equivalent would be approx. 22,813 kWh/a. Peak load would be approx. 15 kW.
- The feed mill has two sets of grinder/mixers, each driven by a 50hp (38kW) 4 cylinder diesel engine. Diesel consumption is approx. 30 l/d (10,950 l/a). The electricity equivalent would be approx. 27,375 kWh/a. The mill operates for 7 h/d; average load would be approx. 25 kW; peak load (with soft starter) would be around 40kW.
- The farm has a single phase grid connection, which is only used for lighting: 10x60W incandescent bulbs for piglet warming plus 2x24W CFL per stable and some additional lighting and TV, all during evening/night-time. Total consumption according to the electricity bill is 850 kWh/month (28 kWh/day; 10,200 kWh/a) at a rate of 0.25 $/kWh.

Total annual diesel demand is thus 20,075 litres – which would be some 50,188 kWh/a when supplied with electricity. The peak load, startup of the feed mill is properly timed, would be 40 kW.

The farm owner indicated to be interested in improving the electricity supply to the farm. They had wanted a 3-phase connection but this required a large investment. The owner would be very interested in changing to a closed stable system, if affordable electricity would be available. For 7 stables, the daily electricity consumption would be in the order of 175kWh/d, or 63,875 kWh/a. The additional peak load would be some 30 kW during daytime.

13.4.2 Supply strategy

The electricity demand at the Chhin Song farm amounts to approx. 30% of the total electricity production potential; if closed stable systems would be used, this would increase to approx. 60%. The remainder can be fed into the grid, if the connection to the MV system is made.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (369 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 48 kW (60 kVA) genset. A somewhat larger genset (e.g. 80 kVA) would be required if the closed stable system would be added as well.

13.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 65.6 t/a (1,641 tCO_{2eq} /a).
- Diesel substitution is 18,068 l/a (48 tCO_{2eq} /a).
- Grid electricity substitution is 160,964 kWh/a (106 tCO_{2eq}/a).
- Total GHG reduction is thus 1,795 tCO_{2eq} /a.

13.6 Biogas plant description

13.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the daily amount of waste water (72 m^3/d) and the recommended retention time of 30 days, digester volume is set at 2,200 m^3. Dimensions of the lagoon will be approx. 50x15x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 60x25m. Note that these dimensions are provisional and will be set during final design.

Waste water will flow from the fattening stables through pipes into a central sedimentation tank, and subsequently into a mixing tank where the solid dung from the sow stables is added. From here it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be distributed to the fruit trees on the premises, or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

13.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 48 kW (60 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer, and transported to the MV grid through a 2 km MV line.

Any excess biogas will be burnt off with a flare.

13.7 Financial analyses

13.7.1 Basic parameters

Table 104 shows the basic parameters used in the financial calculations.

Table 104: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Indicated by farm owner
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas
Grid electricity tariff	US$/kWh	0.25	Actual price level at Ang Khun farm
Feed-in tariff	US$/kWh	0.100	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

13.7.2 Investment costs

Table 92 below gives an overview of the investment costs of the biogas system at Khun Ang farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 105: Investment costs Khun Ang farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	19,000	15	2%
Pumps	1,000	5	5%
Structures	13,000	20	2%
Gas treatment	6,000	10	5%
Generator	21,000	5	10%
Electrical systems	35,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**100,000**	**N/A**	**N/A**
Contingencies	10,000	N/A	N/A
Pre-production financial costs	3,700	N/A	N/A
Total investment costs	**113,700**	**N/A**	**N/A**

As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 10,000 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Also, electrical systems (grid lines, transformer and synchronisation panel) add significantly to the investment costs. One system alternative would be to omit the grid connection, and only supply the own farm - with or without the additional electricity demand of the closed stables.

Net working capital would be US$ 2,139 which is made up of accounts receivable for grid supply (US$ 2,530) minus accounts payable (US$ 391).

13.7.3 Production costs

Table 106 shows the operating and production costs of the biogas system in the first 6 years. Note that in the operating costs, maintenance of the generator takes up the largest part (45%), followed by staff costs (19%) and maintenance of the electrical systems (15%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 13.7.1), these will remain 0 from year 6 onwards.

Table 106: Production costs Khun Ang farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	3,790	3,790	3,790	3,790	3,790	3,790
Operating costs	**4,690**	**4,690**	**4,690**	**4,690**	**4,690**	**4,690**
Depreciation	10,542	10,542	10,542	10,542	10,542	10,542
Financing costs	7,400	5,920	4,440	2,960	1,480	0
Production costs	**22,632**	**21,152**	**19,672**	**18,192**	**16,712**	**15,232**

13.7.4 Revenues

The annual revenues for the biogas system are shown in Table 107 below. Total revenues are 26,507 US$/a; when on-farm electricity demand would increase, this could rise to a level of 35,130 US$/a.

Table 107: Revenues Khun Ang farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement	Litres	18,068	0.50	18,068
Electricity consumption	kWh	9,180	0.25	2,295
Grid supply	kWh	151,784	0.10	15,178
Total revenue	**US$**			**26,507**

13.7.5 Cash flow analysis

Table 108 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). The first years show slightly negative net cash flows due to interests and loan repayments, which would require short term financing or additional equity investments. Particularly in year 5 there is a reinvestment that would require short term financing. Cumulative cash flow becomes positive after year 6.

Table 108: Cash flow Khun Ang farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	34,000	0	0	0	0	0	0
Debt financing	80,000	0	0	0	0	0	0
Short term financing	0	391	0	0	0	0	0
Inflow from operations	0	26,507	26,507	26,507	26,507	26,507	26,507
Total inflow	**114,000**	**26,898**	**26,507**	**26,507**	**26,507**	**26,507**	**26,507**
Increase fixed assets	110,000	0	0	0	0	24,200	0
Increase current assets	0	2,530	0	0	0	0	0
Operating costs	0	4,690	4,690	4,690	4,690	4,690	4,690
Corporate tax	0	775	1,071	1,367	1,663	1,959	2,255
Interest payable	3,700	7,400	5,920	4,440	2,960	1,480	0
Loan repayments	0	16,000	16,000	16,000	16,000	16,000	0
Total outflow	**113,700**	**31,395**	**27,681**	**26,497**	**25,313**	**48,329**	**6,945**
Net cash flow	**300**	**-4,497**	**-1,174**	**10**	**1,194**	**-21,822**	**19,562**
Cumulative	**300**	**-4,197**	**-5,371**	**-5,361**	**-4,167**	**-25,989**	**-6,427**

Table 109 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.139 US$/kWh, which is significantly above the expected grid feed-in tariff but far below the grid supply tariff (0.25 US$/kWh) and the costs of diesel-based energy (>0.25 US$/kWh).

Table 109: Indicators Khun Ang farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.139
IRR	%	12%
NPV	US$	-8,179
Return on Equity	%	12%
Simple Payback Period	years	5.2

13.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l, in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 67 below.

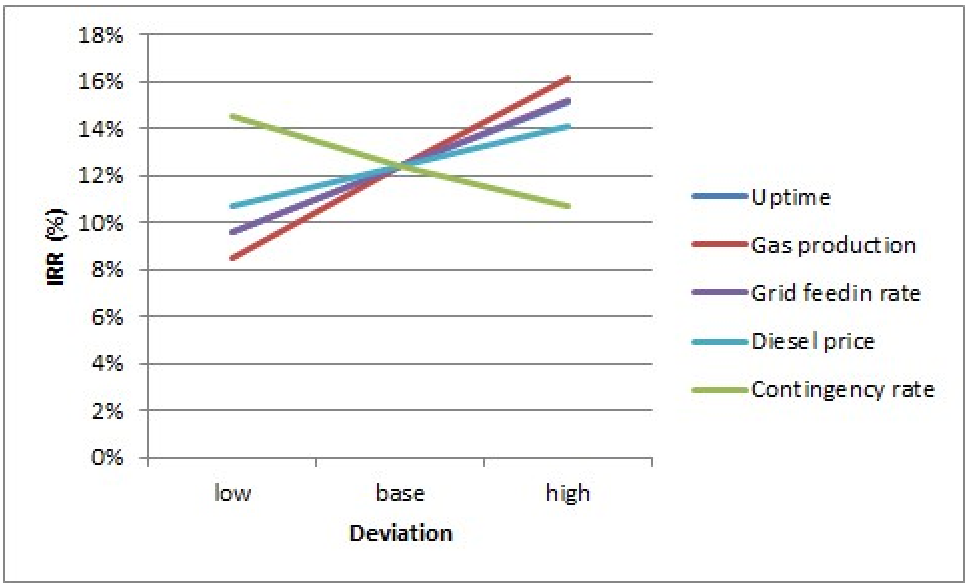

Figure 67: Sensitivity analysis Khun Ang biogas project

The results show that variations in investment costs and diesel price have similar consequences: all result in IRR changes of around 2% points from the base case value. Note that diesel price deviations of ±40% result in IRR changes of approx. ±3.5% from the base case value.

Variations in grid feed-in tariff and generator availability have the same consequences: IRR changes of about 3% points from the base case value. Sensitivity to gas production is highest: deviations of ±20% result in IRR changes of approx. ±4%.

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%), higher diesel price (+20%) and higher investment costs (20% contingency rate) results in an IRR of 16%.
- Reduced generator uptime (80%) plus lower feed-in rate (-20%) result in an IRR of 7%.
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%) lower diesel price (-20%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of 0% (11 years simple payback period).
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%) higher diesel price (+20%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 27% (3 years simple payback period).

Further alterations from the base case have the following effect:

- Increasing on-farm electricity demand by closing the stables will result in a large shift from electricity being sold to the grid (at 0.10 US$/kWh) to electricity consumed on the farm (at 0.25 US$/kWh alternative cost). Project revenue will increase, leading to an IRR of 20% and a payback period below 4 years.
- The system alternative proposed in section 13.7.2, i.e. not investing in the grid connection and thus not receiving income from grid sales, results in a reduction of investment costs of approx. 40,000 US$ but an IRR dropping to 2%. However, if, in this scenario, on-farm electricity demand is increased by adding closed stables, the combination of lower investment costs and higher system output leads to an IRR of 24%.

- Selecting a low-cost solution for the generator will reduce investment costs with approx. 11,000 US$, but because of the shorter lifespan the effect on IRR is limited (14%).

13.8 Conclusions

The average biogas production potential at Khun Ang farm is approx. 369 m^3/d, with little fluctuations. The project features a covered lagoon digester with a volume of 2,200 m^3 and a 48 kW (60 kVA) gas generator. Electricity production potential is approx. 627 kWh/d on average (206,132 kWh/a) which can be used to replace grid-supplied electricity, to replace diesel use for pumping and feed milling, and to supply to the local grid.

Total investment costs of the system is 113,700 US$. In the base case scenario, the Levelised Cost of Electricity is 0.179 which is inbetween the present energy costs for the farmer (from the grid or diesel-based) and the expected grid feed-in tariff. The project IRR is 12% and its simple payback period is 5.2 years. It is most sensitive to deviations in generator availability, biogas production rate and grid feed-in tariff.

Increasing on-farm electricity demand, by applying closed stables, has a high impact on project viability; the increased revenue boosts the IRR to 20%. With increased on-farm demand, the available electricity for feeding into the grid decreases, and making in the investment in the grid connection could be re-considered.

14 FEASIBILITY STUDY: ROS SOKHA FARM

Table 110: Ros Sokha farm location and contact

Farm	Ros Sokha
Village	Tra Paingpring
Commune	Tra Paingpring
District	Teuk Chhou
Province	Kampot
GPS	10.6240N, 104.3681E
Owner	Mr. Ros Sokha 016 812 354

14.1 Introduction

The farm of Mr. Ros Sokha is located in Kampot province, some 15km West of the district capital Teuk Chhou. The owner started a mango plantation on the 28 ha plot in 2004, and started rearing pigs on the same location in 2009. It is a fattening farm, with 3,250 heads in 5 stables; a 6th stable will be constructed next year expanding farm capacity to 3,900 heads.

Figure 68: Overview of Ros Sokha farm

In addition to the mango plantation and the pig farm, the owner also has a guest house and a clinic in Phnom Penh.

14.2 Farm operation

Like many other fattening farms, the farm works with CP Cambodia. However, the arrangement is less common: the owner buys all the inputs (piglets, feed, medicine) from CP and sells all the pigs to CP, but then at a higher price (2.5 US$/kg live weight). Also, there is no all-in, all-out system practiced: each time just one stable is emptied. This means that variation in the number of animals – and thus in waste production – is limited (approx. 15%). Average daily feed consumption is 4 t/d (average 1.23 kg/head/d).

Each of the stables holds 650 heads. Bathing water is changed every day, after the solid dung has been pushed in. Hosing is done twice per week, with a high pressure sprayer.

The farm also has a small biogas system for cooking, but it stopped working early February 2016.

There are 10 workers on the farm, wages are between 150-200 US$/month.

14.3 Biogas feedstock

14.3.1 Manure and urine production

Average daily dung production is estimated at 3.1 tonnes per day, varying between 2.6 and 3.5 t/d. Total dry matter production (including solids from urine) will be approx. 1.2 t/d on average, varying between 1.0 and 1.4 t/d.

Urine production will also vary throughout the cycle, but is on average approx. 10 m^3/d.

The dung, urine and cleaning water runs into 3 ponds through a system of canals; two stables have their own pond (rudimentary), and three of the stables share one pond which is located some 100m south of the stables. Once per year slurry from the ponds is collected and distributed to the mango trees using a slurry truck. Other than that, nothing is done with the contents: water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

Figure 69: One of the stables at Ros Sokha farm

Figure 70: One of the slurry ponds

14.3.2 Water consumption

Water for drinking and cleaning is pumped from 3 wells into a series on reservoirs, using 3 electric pumps. Total consumption of cleaning water (for 6 stables) is estimated at 134 m^3/d:

- Cleaning of baths (daily) consumes some 20 m^3/d for each stable, i.e. 120 m^3/d in total
- Hosing (twice per week) takes some 6 hours each time; water consumption was measured at 22 l/min so water consumption for cleaning one stable is 7.8 m^3. Average daily water consumption for hosing is thus 13.5 m^3/d.

Water evaporation is estimated at 0.5 m^3/d/stable or 3 m^3/d.

14.3.3 Total waste production

Total waste production – water consumption reduction accounted for – is shown in Table 111. Waste production (37 l/head/day) is below the average found in the sector (43 l/head/d) but significantly above the average found in e.g. Vietnam (approx. 30 l/head/d). This is mainly due to the high water consumption by bath water refreshing.

Table 111: Total waste production at Ros Sokha farm

Source	Unit	average	minimum	maximum
Water	t/d	133	133	133
Dung (fresh)	t/d	3.0	2.6	3.5
Urine	t/d	10	8	11
Evaporation	t/d	3.0	3.0	3.0
Total waste water	t/d	143	141	145
DM content	%	0.8%	0.7%	0.9%

14.3.4 Biogas and electricity production potential

Table 112 below gives an overview of the biogas and electricity production potential at Ros Sokha farm. Biogas production is based on 300 m^3/tDM for pig slurry, electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency, due to small size). Annual electricity production potential on the basis of biogas availability would be 217,796 kWh/a; assuming 90% generator set availability, total annual electricity production would be 196,016 kWh/a.

Table 112: Biogas and electricity production potential at Ros Sokha farm

	Unit	Average	Minimum	Maximum
Total biogas	m^3/d	351	298	404
Total electricity	kWh/d	597	507	686
Total electricity (at 90% genset availability)	kWh/a	196,016		

14.4 Energy demand and supply

14.4.1 Energy demand

Energy consumption at Ros Sokha farm concerns the following:

- Water pumping (drinking and cleaning water) is done with 3 electric pumps of 0.75 kW each (2.3 kW total). All pumps are run for approx. 20 h/d, so electricity consumption would be approx. 45 kWh/d (16,425 kWh/a).
- Lighting concerns 75 CFLs of 18W each (1.3 kW) during night-time (12 h/d), so electricity consumption would be approx. 16 kWh/d (5,913 kWh/a).
- There are 4 freezers (3x140W, 1x200W), 1 A/C and 2 TVs. Total consumption is estimated at 31 kWh/d (11,169 kWh/a).

In addition there are 2 diesel fuelled spray water pumps for stable cleaning, consuming each approx. 1 l/h during 6 h/d of operation. Average load will be in the order of 2 kW each; typical electricity consumption if driven by electric pump would be in the order of 24 kWh/d, or 8,760 kWh/a.

Total present electricity demand is thus estimated at some 92 kWh/d (33,507 kWh/a), with an average load of approx. 4kW. This was confirmed by a spot load measurement (3.2 kW for pumps and lighting). If in the future spray pumps will be electric, consumption would increase to 116 kWh/d (42,267 kWh/a). Total peak load will be below 15 kWe.

The electricity is being generated with a 25kVA diesel genset which is running for 20 h/d. According to the owner, total diesel consumption of the farm is 60-70 l/d. Subtracting the diesel for the spray water pumps would bring generator production at some 1.74 kWh/l diesel which is within expected range for a smaller generator running at a low loading rate. Total annual diesel demand would be approx. 21,900 l/a.

Extension of the grid (from REE, still 3 km away) is being planned but is unknown when it will happen.

14.4.2 Supply strategy

The electricity demand at the Ros Sokha farm amounts to approx. 20% of the total electricity production potential. The remainder can be fed into the grid, if the connection to the MV system is made.

In order to convert all biogas to electricity, the generator will need to have sufficient capacity to convert the maximum quantity of biogas (404 m^3/d) in a maximum number of hours per day (e.g. approx. 16 h/d). At 90% loading rate this results in a 48 kW (60 kVA) genset.

14.5 GHG emission reductions

Greenhouse gas reductions from this project were established as follows:

- Methane emission reduction is 66.4 t/a (1,660 tCO_{2eq} /a)
- Diesel substitution is 19,710 l/a (52 tCO_{2eq} /a)
- Grid electricity substitution is 157,976 kWh/a (104 tCO_{2eq}/a)
- Total GHG reduction is thus 1,816 tCO_{2eq} /a

14.6 Biogas plant description

14.6.1 Biogas system

The conversion of solids from the waste water into biogas will take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the daily amount of waste water (145 m^3/d) and the recommended retention time of 30 days, digester volume is set at 4,400 m^3. Dimensions of the lagoon will be approx. 50x25x5 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 60x35m. Note that these dimensions are provisional and will be set during final design.

Waste water will flow from the stables through pipes into a central sedimentation tank, from where it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting content from the lagoon. The digested slurry will be distributed to the fruit trees on the premises, or disposed as currently done with the contents of the waste water lagoon.

The captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

14.6.2 Generator and electrical system

The biogas will be used in a gas generator (spark plug engine) with a capacity of 48 kW (60 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a shorter life span and requires frequent overhaul.

Grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer, and transported to the MV grid through a 3 km MV line.

Any excess biogas will be burnt off with a flare.

14.7 Financial analyses

14.7.1 Basic parameters

Table 113 shows the basic parameters used in the financial calculations.

Table 113: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Average salary found in industry
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas
Feed-in tariff	US$/kWh	0.126	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

14.7.2 Investment costs

Table 114 below gives an overview of the investment costs of the biogas system at Ros Sokha farm. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 114: Investment costs Ros Sokha farm biogas system (base case)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	28,000	15	2%
Pumps	2,000	5	5%
Structures	12,000	20	2%
Gas treatment	6,000	10	5%
Generator	21,000	5	10%
Electrical systems	47,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**121,000**	**N/A**	**N/A**
Contingencies	12,100	N/A	N/A
Pre-production financial costs	4,440	N/A	N/A
Total investment costs	**137,540**	**N/A**	**N/A**

As indicated, the proposed choice of generator is an original gas genset. A modified diesel engine would cost about half; this would reduce investment costs with some 11,000 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

Also, the investment costs of the electrical system are considerable; this is mainly due to the 3 km of MV grid lines that are required to connect to the local REE grid. A system alternative would be implement the biogas system, initially for covering the on-farm demand only (dual fuelling the farm generator or running a gas generator) and invest in a transformer and synchronisation equipment once the MV lines arrive at the farm.

Net working capital is calculated as 2,205 US$; this is built up of accounts receivable (2,633 US$) minus accounts payable (428 US$).

14.7.3 Production costs

Table 115 shows the operating and production costs of the biogas system in the first 6 years. Note that in the operating costs, maintenance of the generator takes up the largest part (41%), followed by staff costs (18%) and maintenance to electrical systems (18%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 14.7.1), these will remain 0 from year 6 onwards.

Table 115: Production costs Ros Sokha farm biogas system (base case)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	4,240	4,240	4,240	4,240	4,240	4,240
Operating costs	**5,140**	**5,140**	**5,140**	**5,140**	**5,140**	**5,140**
Depreciation	12,247	12,247	12,247	12,247	12,247	12,247
Financing costs	8,880	7,104	5,328	3,552	1,776	0
Production costs	**26,267**	**24,491**	**22,715**	**20,939**	**19,163**	**17,387**

14.7.4 Revenues

The annual revenues for the biogas system are shown in Table 116 below. Total revenues are 25,653 US$/a. When on-farm electricity demand is increased, by closing stables,

Table 116: Revenues Ros Sokha farm biogas system (base case)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement	litres	19,710	0.50	9,855
Grid supply	kWh	157,976	0.10	15,798
Total revenue	**US$**			**25,653**

14.7.5 Cash flow analysis

Table 117 below shows the project cash-flow for the first 7 years of the project (total project period is 15 years). Load repayments and interests result in negative net cash flows throughout the loan repayment period; from year6 onwards, net cash flows are positive, with the exception of year 10 when reinvestments are required. After year 7, cumulative cash balance becomes positive.

Table 117: Cash flow Ros Sokha farm biogas system (base case)

Item / Year	0	1	2	3	4	5	6
Equity	42,000	0	0	0	0	0	0
Debt financing	96,000	0	0	0	0	0	0
Short term financing	0	428	0	0	0	0	0
Inflow from operations	0	25,653	25,653	25,653	25,653	25,653	25,653
Total inflow	**138,000**	**26,081**	**25,653**	**25,653**	**25,653**	**25,653**	**25,653**
Increase fixed assets	133,100	0	0	0	0	25,300	0
Increase current assets	0	2,633	0	0	0	0	0
Operating costs	0	5,140	5,140	5,140	5,140	5,140	5,140
Corporate tax	0	0	232	588	943	1,298	1,653
Interest payable	4,440	8,880	7,104	5,328	3,552	1,776	0
Loan repayments	0	19,200	19,200	19,200	19,200	19,200	0
Total outflow	**137,540**	**35,853**	**31,676**	**30,256**	**28,835**	**52,714**	**6,793**
Net cash flow	**460**	**-9,772**	**-6,024**	**-4,603**	**-3,182**	**-27,061**	**18,859**
Cumulative	**460**	**-9,312**	**-15,336**	**-19,939**	**-23,121**	**-50,182**	**-31,323**

Table 118 shows financial indicators calculated from the cash flows. It shows a Levelised Cost of Electricity (LCOE) of 0.171 US$/kWh, which is above the feed-in tariff (0.100 US$/kWh) but substantially below the diesel-based energy production costs (>0.25 US$/kWh).

Table 118: Indicators Ros Sokha farm biogas system (base case)

Item	Unit	Value
LCOE	US$/kWh	0.171
IRR	%	8%
NPV	US$	-35,991
Simple Payback Period	years	6.7

14.7.6 Sensitivity analysis

The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l, in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 71 below.

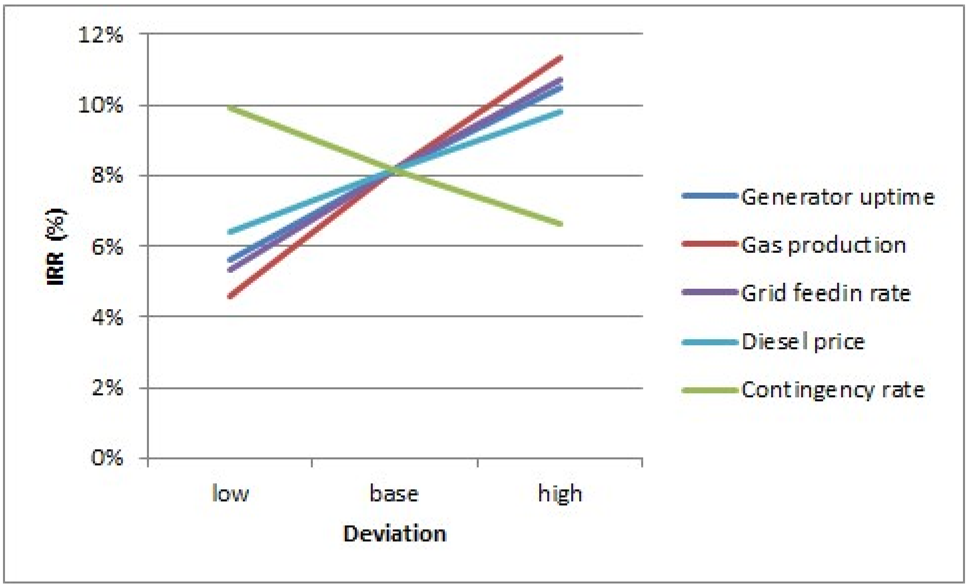

Figure 71: Sensitivity analysis Ros Sokha biogas project

The results show that variations in diesel price (±20%) and contingency rate (10±10%) have similar consequences: both result in IRR changes of less than ±2% points. Even still larger diesel price deviations (±40%) have limited effects – IRR changes of around ±3.5% points.

Grid feed-in tariff and generator availability both have somewhat higher influence, with IRR changes of around ±2-3% points. Gas production has highest influence, with ±20% variations leading to IRR changes of just over ±3% points.

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%), higher diesel price (+20%) and higher investment costs (20% contingency rate) results in an IRR of 11%.
- Reduced generator uptime (80%) plus lower feed-in rate (-20%) result in an IRR of 3%.

- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime. (80%) lower diesel price (-20%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of -4% (14.5 years simple payback period).
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%) higher diesel price (+20%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 21% (3.8 years simple payback period).

Selecting a low-cost solution for the generator will reduce investment costs with approx. 11,000 US$, but because of the shorter lifespan the effect on IRR is limited (increase to 9%).

The alternative indicated in section 14.7.2, implementing the biogas system initially for covering on-farm demand and invest in a transformer and synchronisation equipment once the MV lines arrive at the farm, has a more pronounced effect.

- In both cases, total investment is reduced because there is no investment required for the MV grid lines. Assuming the grid arrives in 2 years, income during these years is reduced because there is no electricity sold to the grid.
- For initial dual fuelling of the existing generator, only part of the diesel consumption (approx. 60%) is reduced during the initial years. The gas generator is purchased when the MV grid arrives. Initial investments are reduced to US$ 62,740 plus US$ 35,200 in year2. IRR is 11%.
- For directly covering all on-farm electricity demand, the gas generator is purchased directly, and all diesel consumption is replaced with biogas generated electricity. Initial investments are reduced to US$ 85,840 plus US$ 12,100 in year2. IRR is 11%.
- In both cases, IRR drops to 9% when the MV grid arrives in year 3.

14.8 Conclusions

The average biogas production potential at Ros Sokha farm is approx. 351 m^3/d, with fluctuations of ±15%. The project features a covered lagoon digester with a volume of 4,400 m^3 and a 48 kW (60 kVA) gas generator. Electricity production potential is approx. 597 kWh/d on average (196,016kWh/a) which can partly be used on the farm and partly fed into the grid.

Total investment costs of the system is 137,540 US$. In the base case scenario, the Levelised Cost of Electricity is 0.212 which is inbetween the grid feed-in tariff and the diesel base energy production costs. The project IRR is 8% and its simple payback period is 6.7 years. Sensitivity is highest to gas production deviations, but also to grid feed-in tariff and generator availability. If the project is initially implemented for on-farm energy, and equipment for grid connection is installed once the MV grid arrives, increases IRR to 11%.

15 FEASIBILITY STUDY: TAING HAING LY FARM

Table 119: Taing Haing Ly farm location and contact

Farm	Taing Haing Ly
Village	Sdao kanleang
Commune	Dei Eth
District	Kean Svay
Province	Kandal
GPS	11.4853N, 105.1119E
Owner	Mr. Taing Haing Ly 012 96 30 88

15.1 Introduction

The pig farm of Taing Haing Ly is located in Kandal province in Central Cambodia, just south of the Mekong river some 20 km east of Phnom Penh. It is a mixed farm, featuring both pig breeding and pig fattening; the average number of animals is approx. 5,200 heads. The numbers of animals and the variation therein are shown in Table 120 below.

Figure 72: Map of Taing Haing Ly pig farm

The farm has a total of 23 stables, keeping fattening pigs, sows, weaners and boar. There is also feed milling and mixing equipment on the farm. On the same plot, the farm owner has a brick burning factory.

15.2 Farm operation

The farm breeds its own pigs for fattening: production of piglets is about 1200-1300 heads per month, which are subsequently weaned and fattened on the farm. Pig feed is prepared on the farm as well, from rice, maize and protein.

The pigs are kept in 23 stables of varying sizes, ranging from 13x80m to 8x40m. All stables are cleaned daily. In the stables of the fattening pigs, the dung is pushed into the baths, which are then changed. Subsequently, the pens are hosed down. In the stables of the sows and the piglets, the solid dung is collected for use in the biogas systems; they are subsequently hosed down.

There is some experience with biogas on the farm: there are three biogas systems, one small fixed dome plant and two 250 m^3 membrane covered plants that the farmer constructed himself. Only one of the plants is in use; the fixed dome system broke down, and the gas from just one of the larger systems is sufficient to cover the farm needs. The gas is used for fuelling three modified gasoline engines that drive water pumps.

15.3 Biogas feedstock

15.3.1 Manure and urine production

Table 120 gives an overview of the production of dung, urine and dry matter therein. The pig slurry from the fattening pig stables is channelled into the two 250 m^3 digesters, situated in the south of the farm premises. The solid dung from the sow stables is added to this. From the biogas units, it is disposed into a large pond (approx. 50x150m). There is no slurry removal; water evaporates, organic solids decompose and the remainder will partly leach into the ground and partly accumulate in the pond.

Table 120: Average livestock, dung and urine production at Taing Haing Ly farm

Animal	Heads	Variation	Fresh dung (t/d)	Urine (m^3/d)	Total DM (t/d)
Fattening pigs	4,500	±10%	3.52	0.23	1.35
Sows	700	N/A	1.09	0.01	0.36
Boar	40	N/A	0.09	0.00	0.03
Total	**2,258**		**4.70**	**0.23**	**1.74**

15.3.2 Water consumption

Water for the Taing Hang Ly farm is pumped from a well into a pond, and from the pond into intermediate storage for buffering and pressurisation. On the basis of spot measurements, observations and indications from farm operators, total water consumption is estimated at 252 m^3 per day:

- Changing of bathing water in fattening stables, every day: approx. 40 l/head/day, or 180 m^3/d for the whole farm.
- Cleaning of pens with hose, every day: this takes approx. 5 h/d with 4 hoses simultaneously at a rate of 60 l/min each, which results in a consumption of 72 m^3/d for the whole farm.

Waste production, 49 l/head/d, is significantly above the average found in the sector (43 l/head/d) and the average found in e.g. Vietnam (approx. 30 l/head/d). A reduction of the water consumption could be obtained by e.g. by closing off water when not in use, or using pressurized water for hosing.

Water evaporation is estimated at 0.5 m^3/d/stable or 11.5 m^3/d in total.

15.3.3 Total waste production

Total waste production is shown in Table 121 below.

Table 121: Total waste production at Taing Haing Ly farm

Source	Unit	average	Minimum	maximum
Water	t/d	252	252	252
Dung (fresh)	t/d	4.7	4.3	5.0
Urine	t/d	12	10	13
Evaporation	t/d	11.5	11.5	11.5
Total slurry	t/d	257	255	258
DM content	%	0.7%	0.6%	0.7%

15.3.4 Biogas and electricity production potential

In the case of Taing Haing Ly farm, biogas potential can be viewed in two ways: in terms of waste potential or in terms of potential output of the existing biogas systems.

- The existing biogas systems only produce a fraction of the biogas potential (estimated 10-20%). Gas production with these systems could be optimised by feeding them a high solids slurry. On the basis of 50 days retention time, the 500 m^3 volume could sustain a daily inflow of 10 m^3 of slurry, which could be some 2.5 t/d of fresh dung and 7.5 m^3 of waste water. This would require daily collection from the stables of some 50% of the solid dung produced.
- If all waste water and dung from all stables would be used, the total biogas yield would be maximised. This would require the construction of a larger covered lagoon system.

Table 81 below gives an overview of the biogas and electricity production potentials of the both. Biogas production is based on 300 m^3/tDM for pig slurry. Electricity production is based on 1.7 kWh/m^3 (approx. 30% generator efficiency).

Table 122: Biogas and electricity production potential at Taing Haing Ly farm

Source	Unit	Average	Minimum	Maximum
Waste availability				
Total biogas	*m^3/d*	*521*	*480*	*561*
Total electricity	*kWh/d*	*885*	*816*	*954*
Total electricity	*kWh/a*	*290,740*		
Existing biogas system				
Total biogas	*m^3/d*	*240*	*240*	*240*
Total electricity	*kWh/d*	*360*	*360*	*360*
Total electricity	*kWh/a*	*118,260*		


Figure 73: One of the stables at Taing Haing Ly


Figure 74: Brick burning factory

15.4 Energy demand and supply

15.4.1 Energy demand

At present, electricity consumption on the farm site consists mainly of the following:

- Feed preparation: the grinding and mixing equipment is driven by three electric motors, (2x7 kW and 1x4 kW) which are all run for approx. 5 hours per day. Total consumption is approx. 90 kWh/d. Startup currents are high (approx. 100A) but these can be reduced using soft starters.
- Incandescent bulbs are used for warming the piglets during night-time: 100 bulbs of 60W (6kW) consuming some 72 kWh/d.
- Consumption for lighting and other uses is small.

Total electricity consumption is thus approx. 162 kWh/d which is confirmed by the electricity bill of January 2016 (4,800 kWh i.e. 155 kWh/d), bringing electricity consumption at approx. 58,400 kWh/a.

Other energy use includes the following:

- Water pumping is done with three car engines (estimated 50hp), together running a total of approx. 16 h/d. Biogas consumption is not metered but assuming a pump load of approx. 3kW each, the consumption would be in the order of 50 m^3/d. If driven electrically, the electricity consumption would be approx. 48 kWh/d (17,520 kWh/a).
- Fuelwood consumption of the brick factory is 10 m^3/d (average price is 12 US$/$m^3$), estimated 2.5 t/d or approx. 900 t/a. At a Net Heating Value of 14 MJ/kg, this would constitute a primary energy consumption of 35 GJ/d.
- Diesel fuel consumption of the clay extruder used at the brick factory (15kW engine) is estimated at 15 litres per day. If driven electrically, consumption would be in the order of 30 kWh/d (9,000 kWh/a).

The electricity is supplied by a local REE at a rate of 0.25 US$/kWh. The farm owner has experimented with producing electricity with biogas, but did not manage to get a stable supply. This could be due to the low capacity of the gas supply lines (the pump engines are supplied through 50m of ½”PVC pipes which restricts the gas flow), poor engine speed regulation and/or improper gas /air mixing.

NB There is no biogas cleaning; gas composition was measured at 72% CH_4, 25% CO_2 and 530 ppm H_2S.

Figure 75: 250 m^3 biogas system at Taing Haing Ly

Figure 76: Biogas fuelled water pumps

15.4.2 Supply strategy

For the use of the biogas, a 64kW (80kVA) gas engine is proposed. It would run for a maximum number of hours (e.g. approx. 16 h/d). It could cover the full load of the farm (including the feed mill and the rice mill, if not run simultaneously) and supply excess power to the grid during daytime and night time.

Apart from having 2 biogas production options (using existing units or using new covered lagoon system – see section 15.3.4), there are multiple energy supply options:

1. Using a generator for producing electricity for use at the farm, and feeding the remainder into the grid. A generator of approx. 64kW (80kVA) would be required.
2. Using a generator for producing electricity for use at the farm, and using excess biogas in the brick burning factory. In order to cover the farm load, here also a 80kVA generator would be required, but no transformer and synchronisation equipment
3. Using all the gas in the brick factory, thus omitting the use of a generator, gas treatment and electrical equipment. It would require installation of two biogas burners with a capacity of 11 m^3/h (in the large biogas scenario) or 5 m^3/h (in the small biogas scenario)

15.5 System selection

Having two biogas production options and three biogas utilisation options results in six possible production / utilisation combinations. A further analysis reveals the following:

- Using the existing digesters has the advantage of reduced investment costs. At the same time, in projects including a generator, gas treatment and electrical equipment, the relative cost savings are modest. In addition, it has a scale disadvantage, and the collection of the solid dung for its optimal utilisation increases operating costs.
- Supplying gas to the factory leads to investment cost reductions (no generator, gas treatment, grid connection equipment) but also to (much) lower revenue as the basis for the gas pricing is the price of the fuel wood it replaces.
- If electricity is being produced for on-farm use, it is most economic to use the same equipment for producing more electricity for the grid, rather than using the excess gas for brick burning.

After further deliberation it was decided to carry out further analyses on two cases:

- A full-scale case, involving a new digester producing the maximum amount of gas for electricity production for on-farm use and grid supply. This scenario will have the highest investment costs, but also the highest revenues.
- A captive power case, utilising the existing digester and producing electricity only for on-farm use. This scenario will have significantly lower investment costs, but also lower revenues.

15.6 GHG emission reductions

Greenhouse gas reductions from this project, in the ***full production*** scenario, are as follows:

- Methane emission reduction is 89.2 t/a (2,230 tCO_{2eq} /a).
- Diesel substitution is 4,050 l/a (11 tCO_{2eq} /a).
- Grid electricity substitution is 266,872 kWh/a (175 tCO_{2eq} /a)[24].
- Total GHG reduction is thus 2,416 tCO_{2eq} /a.

For the ***captive power*** scenario is as follows:

- Methane emission reduction is 41.1 t/a (1,028 tCO_{2eq} /a).
- Diesel substitution is 4,050 l/a (11 tCO_{2eq} /a).
- Grid electricity substitution is 52,560 kWh/a (35 tCO_{2eq} /a).
- Total GHG reduction is thus 1,073 tCO_{2eq} /a.

15.7 Biogas plant description

15.7.1 Biogas system

In the ***full production*** scenario, the conversion of solids from the waste water into biogas will thus take place in a covered lagoon digester. Covered lagoons are low-cost, low complexity digesters which are suitable for the digestion of large volumes of easily digestible substrates in regions where climatic conditions are favourable. It is the most common type of digester found in larger pig farms in the region. The lagoon will be excavated with sloping sides, and surrounded by earth walls. It will be fitted with a liner of High Density Polyethylene (HDPE), and fully covered by a HDPE cover which will capture all of the biogas that is produced.

On the basis of the maximum daily amount of waste water (258 m^3/d) and the recommended retention time of 30 days, digester volume is set at 7,800 m^3. Dimensions of the lagoon will be approx. 60x30x6 metres (LxWxD); the earth walls around it will make the outer dimensions approx. 70x40m. Note that these dimensions are provisional and will be set during final design.

Waste water from fattening stables will flow through pipes into a central sedimentation tank. The waste from sow stables will first flow into two decentral sedimentation tanks, and will be pumped from there into the central sedimentation tank. From here it is pumped into the digester. A circulation pump can be added for mixing the fresh waste water with the digesting

[24] Note that grid electricity substitution is based on actually supplied electricity; this is lower than the electricity production potential as part of the electricity substitutes diesel rather than replacing grid electricity, and part of the electricity will replace current use of biogas for water pumping which is already CO_2 neutral

content from the lagoon. The digested slurry will be distributed to nearby fields, or disposed as currently done with the contents of the waste water lagoon.

In the ***captive power*** scenario, solid dung will be collected and fed to the digesters. On the basis of daily electricity demand (238 kWh/d) and related gas requirements (140m^3/d), a total of 1.5 t/d of fresh dung will need to be collected (approx. 30% of the total dung production), divided over the two digesters, and mixed with approx. 3 parts of waste water (2.3 m^3/d in each digester) in order to get a slurry. With a total volume of 500m^3, the retention time will be 85 days which is more than enough for complete digestion.

In both cases, the captured gas is transported to the generator by underground gas pipe, fitted with water traps for capturing condensate. Gas treatment concerns H_2S removal: this will be done by biological means (air injection into the lagoon gas storage) and subsequently by chemical means (leading the gas through a bed of iron oxide pellets).

15.7.2 Generator and electrical system

In both cases, the biogas will be used in a gas generator (spark plug engine) with a capacity of 64 kW (80 kVA). It is proposed to use a dedicated gas generator set (e.g. Chinese built Cummins engine). Alternatively, a diesel engine that is converted to run on gas could be used; it is cheaper but will have a somewhat shorter life span and requires frequent overhaul.

In the ***full production*** scenario, grid connection will be made using a synchronisation panel (Chinese make) which will assist in determining voltage levels, frequency, phase sequence and phase difference, prior to making the actual grid connection. Subsequently, the voltage will be stepped-up with a 0.4/22 kV transformer which is connected to the MV grid running along the road in front of the farm.

Any excess biogas will be burnt off with a flare.

15.8 Financial analyses

15.8.1 Basic parameters

Table 123 shows the basic parameters used in the financial calculations.

Table 123: Basic parameters

Item	Unit	Value	Remark
Contingency rate	%	10%	Assumption, based on cost data reliability
Interest rate	%	9.25%	Based on prevailing market rate (late 2015)
Discount rate	%	14%	Reflecting the weighted average cost of capital, assuming 70% debt financing at 9% interest and 30% equity at 25% return on equity
Tax rate	%	20%	Corporate tax rate
Staff salary	US$/a	1,800	Indicated by farm owner
Diesel price	US$/l	0.50	Typical price level found at depot stores in rural areas
Grid electricity tariff	US$/kWh	0.25	Actual price level at Taing Haing Ly farm
Feed-in tariff	US$/kWh	0.100	Based on post-2015 bulk purchase price from EDC (0.126 US$/kWh) as set by EAC

Although project financing is to be decided by the project owner, in the analyses a loan of 70% of the project costs is included at the indicated interest rate of 9.25%, with a repayment period of 5 years. Negative cash flows as a result of loan repayments or interest payments are disregarded.

15.8.2 Investment costs

Table 124 and Table 125 below give an overview of the investment costs of the biogas system / generator at Taing Haing Ly farm. In the captive power scenario, investment costs are nearly 60% lower than in the full production scenario. The digester costs are based on indications from existing biogas plants; other main cost items (pumps, generator, electrical systems, gas treatment) are based on supplier quotations and the remainder are estimates. Over-all accuracy will be within ±10%.

Table 124: Investment costs Taing Haing Ly farm biogas system (full production)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	41,000	15	2%
Pumps	3,000	5	5%
Structures	5,000	20	2%
Gas treatment	6,000	10	5%
Generator	25,000	5	10%
Electrical systems	11,000	15	2%
Engineering and installation	5,000	15	N/A
Sub-total	**96,000**	**N/A**	**N/A**
Contingencies	9,600	N/A	N/A
Pre-production financial costs	3,561	N/A	N/A
Total investment costs	**109,161**	**N/A**	**N/A**

In the ***full production*** scenario, net working capital would be US$ 3,156 which is made up of accounts receivable for grid supply (US$ 3,572) minus accounts payable (US$ 416).

Table 125: Investment costs Taing Haing Ly farm biogas system (captive power)

Item	Costs (US$)	Lifetime (years)	Maintenance (% I_o)
Digester	0	15	2%
Pumps	0	5	5%
Structures	5,000	20	2%
Gas treatment	6,000	10	5%
Generator	25,000	5	10%
Electrical systems	0	15	2%
Engineering and installation	3,000	15	N/A
Sub-total	**39,000**	**N/A**	**N/A**
Contingencies	3,900	N/A	N/A
Pre-production financial costs	1,434	N/A	N/A
Total investment costs	**44,334**	**N/A**	**N/A**

In the ***captive power*** scenario, net working capital would consist only of accounts payable and would thus be negative (US$ 542).

As indicated, the proposed choice of generator is an original gas genset. In both cases, a modified diesel engine would cost about half; this would reduce investment costs with 13,200 US$. Note that lifespan is expected to be reduced from 5 to 3 years.

15.8.3 Production costs

Table 126 shows the operating and production costs of the biogas system in the ***full production*** scenario, in the first 6 years. Note that in the operating costs, maintenance of the generator takes up the largest part (50%), followed by staff costs (18%) and maintenance of the digester (16%). The remainder is maintenance for other equipment. Financial costs concerns interest on loan financing (see section 13.7.1), these will remain 0 from year 6 onwards.

Table 126: Production costs Taing Haing Ly farm biogas system (full production)

Item / Year	1	2	3	4	5	6
Staff	900	900	900	900	900	900
Maintenance	4,090	4,090	4,090	4,090	4,090	4,090
Operating costs	**4,990**	**4,990**	**4,990**	**4,990**	**4,990**	**4,990**
Depreciation	11,275	11,275	11,275	11,275	11,275	11,275
Financing costs	7,123	5,698	4,274	2,849	1,425	0
Production costs	**23,388**	**21,963**	**20,539**	**19,114**	**17,690**	**16,265**

Operating and production costs of the biogas system in the ***captive power*** scenario are shown in Table 127. Despite the higher operating costs – due to the labour involved in dung collection and digester filling - production costs are 20-30% below those in the full production scenario. Staff costs amount to 55% of total operating costs; generator maintenance 38%.

Table 127: Production costs Taing Haing Ly farm biogas system (captive power)

Item / Year	1	2	3	4	5	6
Staff	3,600	3,600	3,600	3,600	3,600	3,600
Maintenance	2,900	2,900	2,900	2,900	2,900	2,900
Operating costs	**6,500**	**6,500**	**6,500**	**6,500**	**6,500**	**6,500**
Depreciation	6,655	6,655	6,655	6,655	6,655	6,655
Financing costs	2,868	2,294	1,721	1,147	574	0
Production costs	**16,023**	**15,449**	**14,876**	**14,302**	**13,729**	**13,155**

15.8.4 Revenues

The annual revenues for the biogas system in the ***full production*** scenario are shown in Table 128 below.

Table 128: Revenues Taing Haing Ly farm biogas system (full production)

Item	Unit	Units (units/a)	Unit price (US$/unit)	Revenue (US$/a)
Diesel replacement	litres	4,050	0.50	2,025
Electricity consumption	kWh	52,560	0.25	13,140
Grid supply	kWh	214,312	0.10	21,431
Total revenue	**US$**			**36,596**

In the ***captive power*** scenario, the revenues consist of replacement of diesel and electricity supply, with amounts corresponding to those in Table 128. Total annual revenues are thus 15,165 US$/a, some 60% below this in the full production scenario.

15.8.5 Cash flow analysis

Table 129 below shows the project cash-flow for the first 7 years of the project in the ***full power*** scenario (total project period is 15 years). Net cash flows are positive over the whole project period, except for years 5 and 10 when re-investment in new equipment is required. In both cases, the negative net cash flow does not result in cumulative cash flow dropping below 0.

Table 129: Cash flow Taing Haing Ly farm biogas system (full production)

Item / Year	0	1	2	3	4	5	6
Equity	33,000	0	0	0	0	0	0
Debt financing	77,000	0	0	0	0	0	0
Short term financing	0	416	0	0	0	0	0
Inflow from operations	0	36,596	36,596	36,596	36,596	36,596	36,596
Total inflow	**109,161**	**33,726**	**29,015**	**27,875**	**26,735**	**56,396**	**9,056**
Increase fixed assets	105,600	0	0	0	0	30,800	0
Increase current assets	0	3,572	0	0	0	0	0
Operating costs	0	4,990	4,990	4,990	4,990	4,990	4,990
Corporate tax	0	2,642	2,927	3,212	3,496	3,781	4,066
Interest payable	3,561	7,123	5,698	4,274	2,849	1,425	0
Loan repayments	0	15,400	15,400	15,400	15,400	15,400	0
Total outflow	**109,161**	**33,726**	**29,015**	**27,875**	**26,735**	**56,396**	**9,056**
Net cash flow	**839**	**3,286**	**7,582**	**8,721**	**9,861**	**-19,800**	**27,540**
Cumulative	**839**	**4,125**	**11,706**	**20,427**	**30,288**	**10,489**	**38,029**

Table 130 below shows the cash flows in the ***captive power*** scenario. In this scenario, net cashflows are negative in years 5 and 10, because of reinvestments. These negative cashflows cause negative cumulative cashsflows in years 5-7 and 10-11, but at the end of the project it is positive.

Table 130: Cash flow Taing Haing Ly farm biogas system (captive power)

Item / Year	0	1	2	3	4	5	6
Equity	14,000	0	0	0	0	0	0
Debt financing	31,000	0	0	0	0	0	0
Short term financing	0	542	0	0	0	0	0
Inflow from operations	0	15,165	15,165	15,165	15,165	15,165	15,165
Total inflow	**45,000**	**15,707**	**15,165**	**15,165**	**15,165**	**15,165**	**15,165**
Increase fixed assets	42,900	0	0	0	0	27,500	0
Increase current assets	0	0	0	0	0	0	0
Operating costs	0	6,500	6,500	6,500	6,500	6,500	6,500
Corporate tax	0	0	0	58	173	287	402
Interest payable	1,434	2,868	2,294	1,721	1,147	574	0
Loan repayments	0	6,200	6,200	6,200	6,200	6,200	0
Total outflow	**44,334**	**15,568**	**14,994**	**14,478**	**14,020**	**41,061**	**6,902**
Net cash flow	**666**	**139**	**171**	**687**	**1,145**	**-25,896**	**8,263**
Cumulative	**666**	**805**	**976**	**1,663**	**2,808**	**-23,087**	**-14,824**

Table 131 shows financial indicators calculated from the cash flows, for both cases. For the ***full production*** scenario, the Levelised Cost of Electricity (LCOE) of 0.100 US$/kWh, which equals the expected feed-in rate for electricity but is far below the price of grid power (0.25 US$/kWh). Simple Payback Period is approx. 3.5 years.

In the ***captive power*** scenario, LCOE is 0.239 US$/kWh which is considerably higher than in the full production scenario, but still slightly below the tariff for grid electricity. Simple Payback Period is 11.7 years.

Table 131: Indicators Taing Haing Ly farm biogas system

Item	Unit	Full production	Captive power
LCOE	US$/kWh	0.100	0.239
IRR	%	21%	6%
NPV	US$	38,853	-13,555
Return on Equity	%	28%	5%
Simple Payback Period	years	3.5	5.1

15.8.6 Sensitivity analysis

The cashflow analyses show the best economic results for the full production scenario; the sensitivity analysis is therefore limited to this scenario only. The following variables have been manipulated in order to test their influence on the project indicators:

- Generator availability. In the base case an availability rate of 90% is used; in the sensitivity analysis this has been varied between 80% (increased downtime) and 100% (only scheduled downtime).
- Gas production. In the base case this is 300 m^3/tDM, in the sensitivity analysis the consequences of deviations of ±10% have been assessed.
- Grid feed-in rate. In the base case this is 0.10 US$/kWh; in the sensitivity analysis values of 0.08 and 0.12 US$/kWh have been assessed.
- Diesel price. In the base case this is 0.50 US$/l, in the sensitivity analysis variations of ±20% and ±40% have been assessed.
- Investment costs. Deviations from the cost estimates have been assessed by varying the contingency rate (base case 10%) between 0% and 20%.

The results of the analysis are show in Figure 77 below. The graph shows that the project is almost completely insensitive to variations in diesel price. Fluctuations in generator availability (90±10%) and grid feed-in tariff (±20%) have the same effect on IRR: a change of approx. ±3.5% points from the base value. Deviations in investment costs have modest consequences (approx. ±2.5% points IRR change). Sensitivity to gas production rates is highest: deviations of ±20% result is changes in IRR of about 5% points.

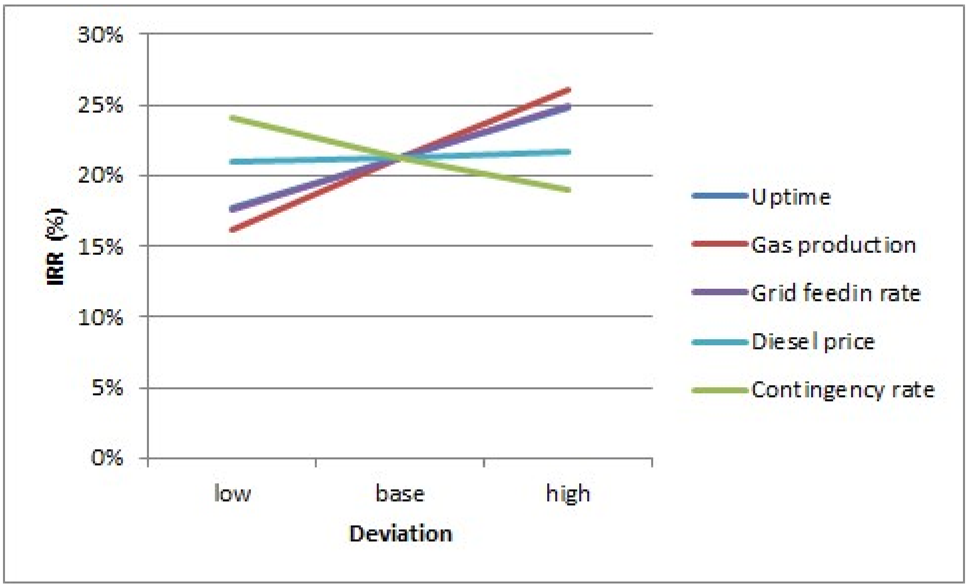

Figure 77: Sensitivity analysis Taing Haing Ly biogas project

Combinations of deviations could result in larger fluctuations in IRR. There are many different combinations possible; some examples:

- Increased gas production (+20%), higher generator availability (100%) and higher investment costs (20% contingency rate) results in an IRR of 27%.
- Reduced generator uptime (80%) plus lower feed-in rate (-20%) result in an IRR of 14%.
- In an all-negative scenario, reduced gas production (+20%), reduced generator uptime (80%) lower diesel price (-20%), lower feed-in tariff (-20%), higher contingency rate (20%), results in an IRR of 8% (6.2 years simple payback period).
- In an all-positive scenario, increased gas production (+20%), increased generator uptime (100%) higher diesel price (+20%), higher feed-in tariff (+20%), lower contingency rate (0%), results in an IRR of 39% (2 years simple payback period).

NB Selecting a low-cost solution for the generator will result in IRR increasing from 21% to 24%. Reducing water consumption with 25% will increase IRR to 23%.

15.9 Conclusions

The average biogas production potential at Taing Haing Ly farm is approx. 521 m^3/d, with slight fluctuations. Both a full production scenario and a captive power scenario have been assessed:

- The full production scenario features a covered lagoon digester with a volume of 7,800 m^3 and a 64 kW (80 kVA) gas generator. Electricity production potential is approx. 885 kWh/d on average (290,740 kWh/a) which can partly be used on the farm and partly fed into the local REE grid.
- In the captive power scenario, the existing biogas systems (2x250m^3) already in place could be utilised. They could be fed with 1.5 t/d of fresh dung and 4.5m3 of waste water, thus producing 140m^3/d of biogas. This would be used in a 64 kW (80 kVA) generator, producing 238 kWh/d of electricity for on-farm use.

Total investment costs of the ***full production*** system is 109,161 US$; for the ***captive power*** system it is 44,334 US$. However, the captive power scenario has much lower revenue, resulting in poor project economics (IRR of 6%, Simple Payback period of 5.1 years). In the full production scenario, the project IRR is 21% and its simple payback period is 3.5 years. The Levelised Cost of Electricity is 0.100 which is equal to the expected grid feed-in rate but well below the price that the farm owner pays for electricity from the local REE. It is most sensitive to deviations in biogas production rate, generator availability, and grid feed-in tariff.

Final note: although the full production scenario is more attractive than the captive power one, it might be worth considering a two phase project approach. In the first phase, a generator and gas treatment system are being installed. The system could be run for captive power production only. When the generator has worker satisfactorily for 1-2 years, a larger biogas system could be installed, along with equipment for grid feed-in.

16 CONCLUSIONS AND RECOMMENDATIONS

16.1 Conclusions

16.1.1 General conclusions of the feasibility studies

1. Feasibility studies on biogas production have been carried out at 12 pig farms in 7 provinces all over Cambodia. It concerned farms of different types (fattening / mixed), scales (1,200 – 15,835 heads), and energy supply situations (on-grid / off grid). Table 132 gives an overview of the main technical parameters of each farm.

Table 132: Overview of FS technical results

#	Name	Animals (heads)	Farm type	Digester (m^3)	Biogas (m^3/d)	Genset (kVA)	Genset (kW)	E prod. (kWh/a)	E cons. (kWh/a)	Grid supply (kWh/a)	GHG red. (t/a)
1	Sar Ratha	1,488	Mixed	2,300	240	50	40	118,418	64,799	53,619	846
2	Pich Robin	4,800	Fattening	4,700	432	125	100	241,250	0	120,625	2,122
3	Te Sopheak	1,200	Fattening	1,900	108	30	24	53,217	4,665	24,276	531
4	Nget Sovannaroth	1,830	Fattening	2,500	165	50	40	91,977	13,414	78,563	843
5	Eang Souleng	1,200	Fattening	1,900	108	30	24	53,217	6,570	23,324	532
6	Chren Vorn	2,400	Fattening	3,200	216	50	40	120,625	3,942	116,683	1,107
7	BVB Investment	15,835	Mixed	14,200	1,592	300	240	993,896	335,333	658,564	7,465
8	Neang Chantha	2,258	Mixed	3,300	245	40	32	136,776	42,236	47,270	1,020
9	Chhin Song	4,800	Fattening	6,200	432	125	100	241,250	76,610	164,641	2,201
10	Khun Ang	3,856	Mixed	2,200	369	60	48	206,132	54,349	151,784	1,795
11	Ros Sokha	3,900	Fattening	4,400	351	60	48	196,016	38,040	157,976	1,816
12	Taing Haing Ly	5,240	Mixed	7,800	521	80	64	290,740	76,428	214,312	2,416

2. Of each project, a financial analysis has been carried out. The main results of the analyses are show in Table 133 below.

Table 133: Overview of FS financial analysis results

#	Name	Investment costs (US$)	Operating costs (US$/a)	Revenue (US$/a)	LCOE (US$/kWh)	IRR (%)	SPP (years)
1	Sar Ratha	113,654	8,039	22,630	0.279	5%	7.8
2	Pich Robin	101,184	4,150	12,063	0.231	-7%	13
3	Te Sopheak	63,681	2,695	3,278	0.621	N/A	109
4	Nget Sovannaroth	86,421	4,020	10,238	0.251	-5%	14
5	Eang Souleng	63,681	2,695	3,520	0.564	N/A	77
6	Chren Vorn	175,089	5,640	13,311	0.344	-8%	23
7	BVB Investment	204,614	11,710	126,640	0.058	45%	1.8
8	Neang Chantha	77,298	3,020	11,120	0.223	1%	9.5
9	Chhin Song	104,576	5,710	30,398	0.122	16%	4.2
10	Khun Ang	113,700	4,690	26,507	0.139	12%	5.2
11	Ros Sokha	137,540	5,140	25,653	0.171	8%	6.7
12	Taing Haing Ly	109,161	4,990	36,596	0.100	21%	3.5

3. An analysis of the critical factors for project economics reveals the following:
    - Project scale is one of the most important factors, because of its influence on investment and operating costs (both subject to economies of scale) and higher technical efficiencies converting biogas to electricity. The results in tables 132 and 133 show that the two smallest farms have the poorest economic outlook, while the largest farm has the best outlook.
    - On-farm energy demand is an important factor, as the rates at which (excess) energy can be sold are always lower than the rates at which energy is currently produced (i.e. with diesel) or supplied (from a grid). Some farms have only little diesel consumption for water pumping, while others are introducing closed barn systems which increases electricity demand. For many farm owners, access to low cost electricity is a prerequisite for switching to more energy intensive farming systems.
    - Farms where both maximum electricity production and captive power only scenarios were assessed, show that maximum electricity production cases are generally (much) more economical that captive power scenarios.
    - The location of the farm is of importance. On the one hand because farms situated at a distance to the grid would need to invest in the infrastructure required to supply electricity to the grid. On the other hand, electricity demand varies between concession areas, notably between EdC (who is only interested in buying electricity during dry season when hydropower potential is low) and local REEs (whose demand is stable throughout the year.
    - Type of farm (fattening or mixed) is of some importance. Most fattening farms run two “all-in, all-out” cycles each year, which means that twice per year the farm is emptied and new piglets are brought in. This results in large fluctuations in dung production, and consequently to biogas and electricity production potential.
    - One factor that is found in all farms is the high water consumption, for stable cleaning and (especially) for changing animal bath water. Average water consumption is approx. 37 l/head/d, ranging between 19 and 48 l/head/d.

4. Judging from the results in Table 134, of the 12 farms there are 3 where biogas shows good or reasonable business potential:
    - The project on the farm of ***BVB Investment Corporation*** has the strongest business potential (IRR 43%). It has a large scale and considerable on-farm energy demand. Sensitivity analysis show that even lower (or no) returns from grid sales still results in acceptable IRR levels. Tailoring the project to captive power production only results in an IRR of34%.
    - The project on ***Taing Haing Ly*** farm shows good business potential (IRR 21%). The project has a medium scale, on-farm energy demand is good and the potential costs savings are high due to the high electricity tariff. It is also possible to start with a captive power project first - which is less economical but has lower investment costs - and invest in a larger biogas system later on. A project addressing only captive power has an IRR of6%.
    - The project on ***Chhin Song*** farm shows reasonable business potential (IRR 16%). project has a medium scale, and the farm owner holds an electricity supply concession in his area so al electricity can be distributed in his own grid, off-setting

electricity purchased from EdC. Producing power for captive use only is less economic(IRR -4%).

5. Of the 12 farms, there are 4 where the business potential of biogas is such that a project could be implemented if an incentive is provided.
    - The project on the farm of ***Khun Ang*** (IRR 12%) has a medium scale but due to exceptional low water consumption the biogas system is among the smallest. There is considerable on-farm energy demand. Main drawback is the investment required to connect to the MV grid of the local REE (35% of total system costs).
    - The project of ***Ros Sokha*** (IRR 8%) also has a medium scale and considerable on-farm energy demand. Here also, the investment required to connect to the MV grid of the local REE is a bottleneck (39% of total system costs). In potential, the project could start and produce gas for the farm only, and connect to the grid once the MV lines have reached the farm.
    - The project of ***Sar Ratha*** (IRR 5%) is relatively small; an advantage is the presence of other animals (cattle, chicken) whose dung can be added to increase biogas production. A further opportunity would be to use part of the energy for rice milling – at the same time this is would be a precondition to the viability of the project. Because of the high portion of own power consumption, a captive power project shows similar economics.
    - The project of ***Neang Chantha*** (1%) has medium scale, and is situated on the MV grid line. On-farm energy demand is considerable but water consumption would need to be reduced considerably. If electricity could be supplied to the EdC grid throughout the year, IRR would increase to 8%.

6. Of the 12 farms, there are 4 where the business potential of biogas is limited, with little outlook for a viable project unless very high financial incentives are offered.
    - The projects at ***Te Sopheak*** and ***Eang Souleng*** are very similar: both are small, and gas production varies strongly because of the “all-in, all-out” system. On-farm energy demand is low, and opportunities for supplying to the (EdC) grid are limited to the dry season.
    - The projects at ***Nget Sovannaroth*** and ***Chren Vorn*** are small, and on-farm energy demand is low. Payback periods are 14 years and 23 years, respectively.

7. Under prevailing conditions, the project at ***Pich Robin*** farm would classify as having limited business potential (IRR -7%, Payback period is 13 years). It is medium scale but there is virtually no on-farm energy demand. Gas production varies strongly because of the “all-in, all-out” system. A main barrier is the limited opportunity for supplying to the EdC grid; however, if year-round access could be negotiated with EdC (e.g. with support from GEF project partners) the IRR would increase to 9%. Alternatively, if the farm would develop substantial energy demand by switching to closed stables, IRR would increase to 3%.

8. Despite the lower investment costs, using modified truck engines seems to have limited effect on project viability, because of the shorter expected lifetime.

9. The combined generation capacity of all 12 farms amounts to 1,000 kVA (1,000 kW); the combined capacity of all farms with good or medium business opportunities amounts to 840 kVA (672 kW). If Kuch Sokha farm (already has a digester but no generator) would be included, this would bring combined capacity to 1,040 kVA (832 kW).

10. The combined GHG emission reductions, from avoided methane emissions, diesel consumption reduction and grid power substitution, amounts to 22,694 tCO_2eq/a. GHG emission reductions of all farms with good or medium business opportunities amounts to 19,681 tCO_2eq/a.

16.1.2 Conclusions of the existing biogas plants

11. In total, the performance of four existing biogas plants has been assessed. In general, all these biogas systems seem to be operating as well as can be expected. However, gas treatment (particularly H_2S removal) is not applied in any of the biogas systems, which affects biogas utilisation equipment lifetime. Also, in most farms there is no gas metering so digester output and / or generator performance is unknown.

12. The system at the starch factory of ***Battambang Agro Industry (BAI)*** features a 41,000 m^3 Anaerobic Baffled Reactor for the treatment of the company wastewater. Biogas production is approx. 16-17 thousand m^3/d if the starch factory is operating at full capacity. The gas is used in a thermal oil boiler, producing process heat for the factory. The system started up three years ago; it is now working well, and small quantities of excess biogas are being produced (flared).

13. The system at the pig farm of the ***Mong Reththy group*** features 4 covered lagoon biogas units with a combined volume of approx. 76,000 m^3. The biogas (estimated 3,100 m^3/d) is used in 2 gas generators, converted from LPG (original rating 1.25 MVA each), supplying the farm and the night load in surrounding villages. Further extension of the farm capacity will increase gas and electricity production potential.

14. The pig farm of ***Sim Chanrith*** is a pig breeding farm; it has a digester with a capacity of approx. 1800 m^3 for dual fuelling two diesel generators. Average biogas production is estimated at 120 m^3/d, replacing approx. 45 l/d of diesel (40% of generator consumption). Higher replacement levels could be achieved only when more biogas is produced.

15. The system at the pig farm of ***Kuch Sokha*** features a 15,000 m^3 covered lagoon that was started up early 2016. Average biogas production potential is estimated at 630 m^3/d, with large fluctuations because of the “all-out, all-in” system applied. There is currently no generator installed; a generator with a capacity of 200 kVA would be required to consume all biogas, or 100 kVA to cover on-farm demand. Investments in a larger generator and grid connection equipment are estimated at 72,600 USD with a simple payback period of 1.3 years; for the smaller system these are 46,200 USD and 1.5 years, respectively.

16.1.3 Conclusions on market conditions for biogas in Cambodian piggery sector

16. The electricity market in Cambodia is organised around a national electricity company EdC and a large number of private concession holders (REEs) that distribute (and sometimes produce) electricity in their own areas. The possibilities of selling excess electricity depends on the demand of the local REE (or EdC, if that is the concession holder in that area). In principle, all REE's that have been approached are interested in buying power, if the price is right and the supply reliable. EdC has indicated only to be interested in buying electricity during the dry season.

17. As an alternative to electricity production, biogas can be distributed as a gaseous fuel. It can be distributed as a cooking fuel through local pipe network, but in the rural areas where most farms are situated, there is little purchasing power for modern cooking fuels. It can also be upgraded and bottled, for use in households or for automotive uses; however, unlike LPG, it requires storage under high pressure (>200 bar) in heavy cylinders in order to reach a sufficient volumetric energy density. There is currently no client base and under current energy market conditions (low fuel prices), the costs of upgrading, pressurisation and distribution are much higher than the expected revenues.

18. Digested effluent from biogas systems (digestate) has a considerable nitrogen, phosphorous and potassium content (estimated at 13%, 3% and 6% of dry matter weight, respectively) and can be used as organic fertiliser. Main barrier is the low solids content of the effluent, which is difficult to increase without losing substantial parts of the nutrients. As such, distribution of effluent should be done by truck or irrigation canals, both of which have limited reach. Storage of large quantities of effluent is practically impossible so it can only be applied if and when it is produced. In fattening farms, the "all-in, all-out" system results in considerable fluctuations in digestate dry matter content.

19. In general, obtaining revenue from carbon credits is increasingly difficult. The scale of the cumulative greenhouse gas reductions from the biogas projects is relatively small; price levels of certified emission reductions are low (between 2-3 US$/t$CO_2$eq); and project development costs and recurring costs are high. The chances of successfully developing a carbon credit project component are deemed small.

20. A list of equipment suppliers in the region is included in section 2.8. Worth noting is that there is a Cambodian engineering and construction firm that has experience with biogas plant installation, including gas treatment systems and generators. Further, the feed and livestock company C.P. Cambodia has taken a position as supplier of biogas systems, in collaboration with regional construction companies.

16.2 Recommendations

16.2.1 Recommendations for pig farms

1. For the three farms with good business potential (***BVB Investment Corporation***, ***Taing Haing Ly***, ***Chhin Song***) it is recommended to proceed with the further development of their biogas project. This includes, on the short term:
    - Opening negotiations with the local REE in their area with respect to the conditions for supplying electricity to the grid. Conditions laid out in the power purchasing agreements between REEs and EdC may for a basis on the points to agree on.
    - Contacting system suppliers for tailored quotations for the hardware and installation services to be supplied. The list in section 2.8 could form a starting point. However, it may be beneficial for the negotiations to coordinate with the GEF project, so that system suppliers could be approached as a group of farms.
    - Liaising with UNIDO, discussing the kind of support that could be expected from their side. This could be financial support (subsidy or access to loan capital), support in negotiations with REEs or hardware suppliers.

2. Particularly for Taing Haing Ly, the owner could consider to first invest in a generator system, running on the biogas from his existing biogas units (to be optimised) and powering his own on-farm equipment (captive power). This would limit investment costs to 44,334 US$. If this is running well, he could invest in a larger biogas system and grid feed-in equipment in a later stage.

3. For the farms ***Khun Ang***, ***Ros Sokha***, ***Sar Ratha*** and ***Neang Chantha***, financial support would be required in order to arrive at a viable project. It is recommended to first discuss the nature and level of support that can be provided by the GEF project, and the conditions under which the support can be provided. Subsequently, farm owners could start talks with local REEs on grid supply conditions, and contact hardware suppliers.

4. For the farms ***Neang Chantha*** and ***Pich Robin***, a further attempt could be made to change the position of EdC with respect to the possibility of supplying to the grid year-round. It is recommended to liaise with UNIDO, possibly gaining support from government bodies to strengthen their position. In addition, Mr. ***Pich Robin*** could consider switching to closed stables in combination with developing a biogas project.

5. For the farms of ***Te Sopheak***, ***Eang Souleng***, ***Nget Sovannaroth*** and ***Chren Vorn***, business opportunities in biogas are very limited. Further development of a biogas project could be considered if they could source high levels of investment support (>50% of the investment costs). Alternatively, they could attempt to interest neighbouring farms (<500m distance) in jointly developing a biogas project. If they do manage to form a group in the future, they could approach the GEF project to determine viability of their plans and discuss possibilities for support.

16.2.2 Recommendations for existing biogas plant owners

6. Main recommendations for ***Battambang Agro Industry (BAI)***:
   - Experiment with using waste water directly in the ABR, omitting intermediate storage, as this would increase the cumulative COD and thus the gas production of the digester.
   - Other residues from starch production (fibre) could possibly be used for process heat production; the biogas could then be used for electricity production (approx. 2 MVA).
   - If excess biogas production continues (and increases), a generator could be installed for electricity production. 3,000 m^3/d of excess gas would require a 400 kVA generator.

7. Main recommendations for ***Mong Reththy group*** farm:
   - Gas treatment. There is currently only a fabric filter that is ineffective to H_2S and water vapour. Especially H_2S reduction should be implemented in order to prolong the lifetime of the generators.
   - Gas quality and quantity monitoring could help determining generator efficiency, finding the best air-gas mixture, help determining the effectiveness of gas treatment, and provide insight in the functioning of the biogas plant.
   - Gas-to-air mixture regulation. Gas mixing is now done manually; it is advised to determine whether this is affecting system output, and if so, whether an automatic regulation would increase system performance.
   - Generator load optimization. If the generators could run parallel to the grid (i.e. synchronised), generator load and thus efficiency could possibly be optimised. It would also increase the amount of electricity that could be supplied, with a view of planned farm capacity extensions.

8. Main recommendations for ***Sim Chanrith*** farm:
   - Gas treatment. There is currently no gas treatment; engine lifetime is approx. 2 years, which could be increase by applying measures for H_2S reduction. The investment would be approx. 3,000 USD with a repayment period of less than 2 years.
   - Metering. By installing a gas and an electricity meter, digester output and generator performance can be monitored.
   - Adding co-substrates (e.g. agro-processing residues) could increase digester output, and thus the amount of diesel replaced.
   - Installation of a speed regulator on the engines will increase power quality (constant frequency).

9. Main recommendations for ***Kuch Sokha*** farm:
   - Verifying on-farm electrical load pattern, and discussing options for grid supply with the local REE, in order to decide whether to go for a generator for on-farm use (approx. 100 kVA), or for off-farm use plus grid supply (using all biogas, requiring approx. 200 kVA).

- In case of choosing a smaller generator, peak-load reductions for pumps and fans should be considered.
- In any case, if a generator is installed, a treatment system for the biogas should be installed as well.

16.2.3 Recommendations to GEF project

10. On the basis of the outcome of the technical and financial analyses it is recommended to provide financial support to a number of farms, in order to improve the business case and/or incentivise the project owners.

11. Projects that show good business opportunity, but where financial incentive (plus optional loan financing) could be considered include ***BVB Investment Corporation***, ***Taing Haing Ly*** and ***Chhin Song***.

12. UNIDO and GEF project partners should consider making further efforts to convince EdC to purchase electricity outside the dry season, as this would make a large difference to the projects of Neang Chantha and Pich Robin. Possibly, the project could gather government support in order to improve their position vis-à-vis EdC.

13. In addition, GEF project partners could support the different farm owners by facilitating discussions with the different REEs, on grid supply conditions. UNIDO has already reached out to all of the REEs, and could set up (and participate in) meetings between project owners and REEs.

14. Possibly, investment cost reductions for the farm owners can be achieved if they jointly approach hardware suppliers, thereby increasing the potential sales volume. UNIDO could play a coordinating and/or facilitating role in this.

15. Over-all, the GEF project should consider supporting biogas projects with advice and/or financial incentives for the installation of biogas treatment systems, as a means of improving practises in the developing biogas sector. Similarly, the project should consider stimulating the installation of gas and electricity metering equipment, in order to help project owners with monitoring the performance of their systems, and also as a means of learning from ongoing projects. For example, the installation of such equipment, and the communication of production data, could be made one of the conditions to financial support to any of the projects.

16. If it is the intention of the GEF project to stimulate the implementation of equipment meeting certain quality standards (e.g. durable and efficient gas generators), additional financial support to project owners could be considered. The project could consider e.g. covering the additional investment costs in comparison to an alternative generator solution (e.g. modified diesel engine).